Technical Report HL-91-10
July 1997

US Army Corps
of Engineers
Waterways Experiment
Station

Red River Waterway, Lock and Dam 3

Report 3
Sedimentation Conditions
Hydraulic Model Investigation

by Randy A. McCollum

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Prepared for U.S. Army Engineer District, Vicksburg

PRINTED ON RECYCLED PAPER

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U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Report 3 of a Series

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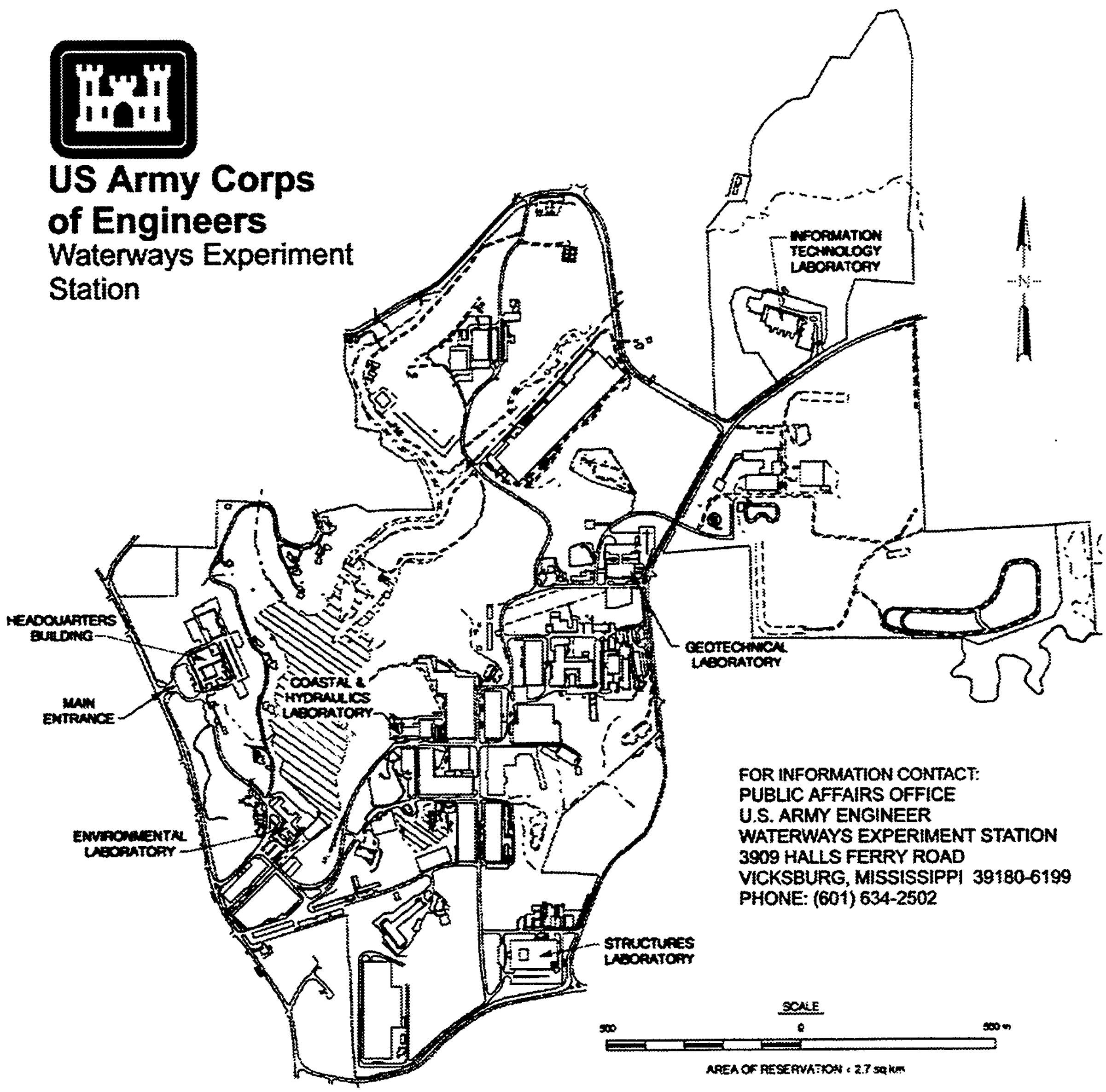

Waterways Experiment Station Cataloging-in-Publication Data

McCollum, Randy A.
Red River Waterway, Lock and Dam 3. Report 3, Sedimentation conditions hydraulic model investigation / by Randy A. McCollum ; prepared for U.S. Army Engineer District, Vicksburg.
57 p. : ill. ; 28 cm. — (Technical report ; HL-91-10 rept.3)
Includes bibliographical references.
1. Sediment transport — Red River (Tex.-La.) 2. Locks (Hydraulic engineering) 3. Movable bed models (Hydraulic engineering) I. United States. Army. Corps of Engineers. Vicksburg District. III. U.S. Army Engineer Waterways Experiment Station. IV. Hydraulics Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Title: Sedimentation conditions hydraulic model investigation. VII. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-91-10 rept.3.
TA7 W34 no.HL-91-10 rept.3

Contents

Preface

The model investigation reported herein was conducted for the U.S. Army Engineer District, New Orleans (LMN), and U.S. Army Engineer District, Vicksburg (LMK), by the U.S. Army Engineer Waterways Experiment Station (WES) during the period March 1978 to March 1990.

In addition to the hydraulic movable-bed model study, two physical model studies and two numerical model studies were conducted at WES. The additional studies included a fixed-bed navigation model study (Report 2); a hydraulic structures model study (Report 4); a numerical model sedimentation study of upstream and downstream approaches to Lock and Dam No. 4 (Report 5); and a numerical model sedimentation study of the Red River upstream and downstream of Lock and Dam No. 4 (Report 6). This is Report 3 of the series. Report 1, to be published later, will summarize all of the model studies.

At the time of report publication, the Director of the Coastal and Hydraulics Laboratory was Dr. James R. Houston. The first-line review was conducted by Mr. T. J. Pokrefke, Acting Chief of the Waterways and Estuaries Division. The engineer in immediate charge of the study during model testing was Mr. C. W. O'Neal, Chief of the River Regulation Branch. The report was prepared by Mr. R. A. McCollum of the Navigation Division, assisted by Messrs. J. L. McGregor and D. N. Mobley and Ms. D. C. Derrick and M. Edris.

During the course of the model study, representatives from the Headquarters, U.S. Army Corps of Engineers, the U.S. Army Engineer Division, Lower Mississippi Valley, LMN, and LMK visited WES to observe model tests and discuss test results. LMN and LMK were kept informed of the progress of the study through monthly progress reports and periodic transmittal of preliminary test results.

This report is being published by the WES Coastal and Hydraulics Laboratory (CHL). The CHL was formed in October 1996 with the merger of the WES Coastal Engineering Research Center and the Hydraulics Laboratory. Dr. James R. Houston is the Director of the CHL, and Messrs. Richard A. Sager and Charles C. Calhoun, Jr., are Assistant Directors.

Commander of WES at the time of publication of this report was COL Bruce K. Howard. The Director of WES was Dr. Robert W. Whalin.

CONVERSION FACTORS, NON-SI TO SI UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1.609344	kilometers

1 Introduction

Location and Description of Prototype

The Red River flows easterly from the northwest portion of Texas along the border between Texas and Oklahoma through southwestern Arkansas into northwestern Louisiana then southeasterly to join the Old River and form the Atchafalaya River (Figure 1). Flow in the upper part of the Red River is controlled by releases from Denison Dam, which is located on the Texas-Oklahoma state line. Flow from the Mississippi River through Old River Diversion Channel into the Atchafalaya River has considerable backwater effect on upstream stages including the lower Red River. A 75- by 1,200-ft[1] lock at the mouth of Old River provides navigation between the Mississippi, Red, and Atchafalaya Rivers.

The Red River has large fluctuations in stage, a shifting bed, caving banks, and unpredictable shoaling. The controlling depths of natural conditions in the Red River have averaged about 6 ft from the mouth to Alexandria, LA, and about 5 ft from Alexandria to Shreveport, LA, from January to July and generally less the remainder of the year. The controlling depths during some periods are as low as 1 to 2 ft in the Alexandria to Shreveport reach. The movement of cargo by barges in the Red River has been limited due to long periods of low flows, narrow bends of short radii, and a heavy sediment load.

Plan of Development

Public Law 90-483, enacted by the 90th Congress on 13 August 1968, authorized the Red River Waterway Project. The project is authorized to improve the Red River and its tributaries in Louisiana, Arkansas, Texas, and Oklahoma through coordinated development to serve navigation, bank stabilization, flood control, recreation, fish and wildlife, and water quality control. The navigation reach is intended to establish a 9-ft-deep by 200-ft-wide navigation channel, approximately 305 miles long, from Old River to Lake O' the Pines near Daingerfield, TX, by a system of nine locks and dams, a number of

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vii.

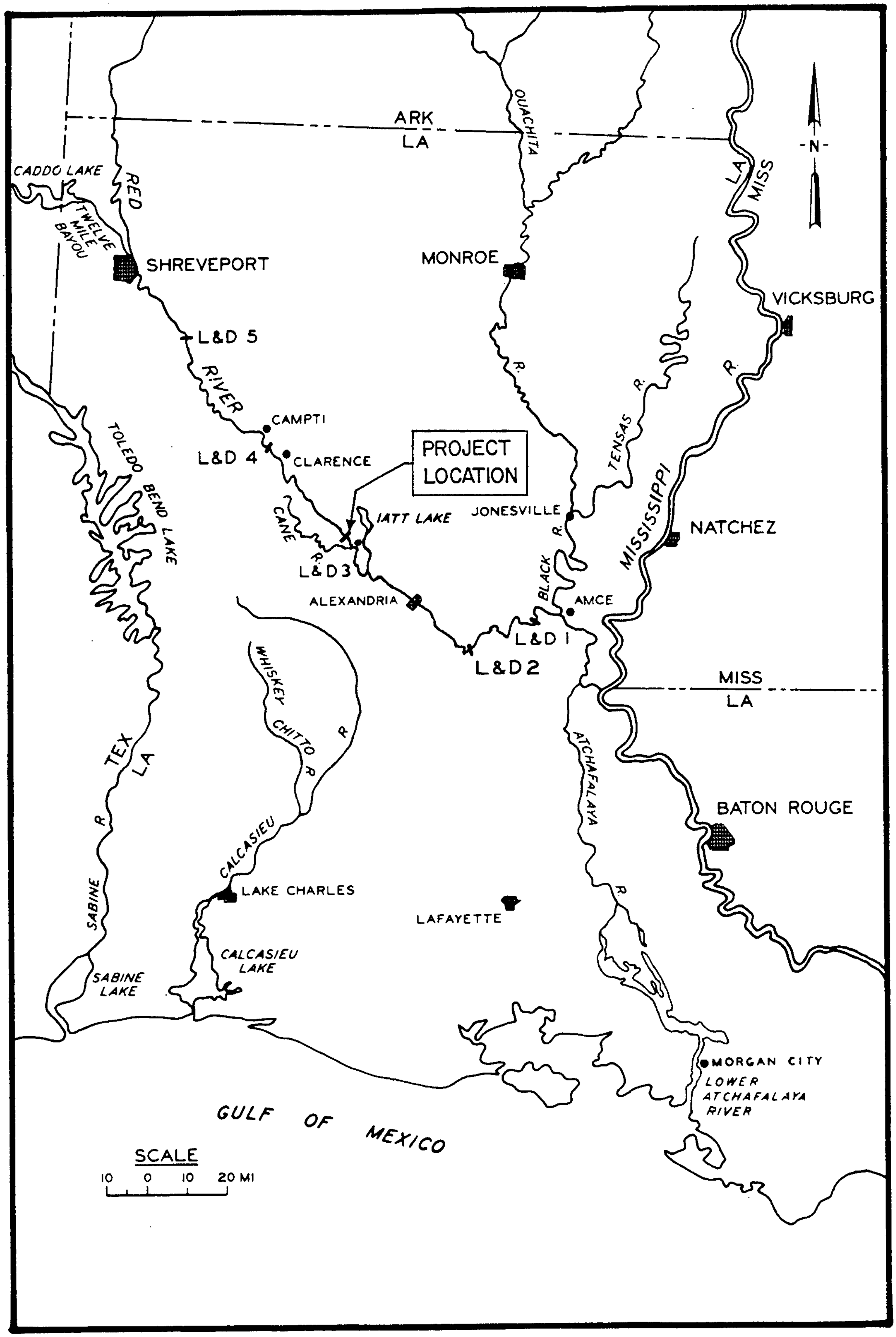

Figure 1. Location map

cutoffs, extensive channel realignment, and channel training and stabilization works. The project consists of four distinct reaches: (a) Mississippi River to Shreveport, LA; (b) Shreveport to Daingerfield by Twelve Mile Bayou; (c) Shreveport to Index, AR; and (d) Index to Denison Dam, TX. The Appropriations Act of 1971, approved 7 October 1970 as Public Law 91-439, provided authority to initiate preconstruction planning in the Mississippi River-to-Shreveport Reach, the only reach pertinent to this study.

Lock and Dam 3

Lock and Dam 3 is located in a cutoff channel between river miles 140 and 142.2 (Figure 1). Lock and Dam 3 is the third navigation structure on the Red River and will consist of a lock on the left side of the cutoff channel and the dam on the right side. The lock has a usable chamber of 84 ft by 685 ft with an upper sill to el 70[2], a floor to el 44, a lower sill to el 46, and lock walls to el 103. The dam is 423 ft long with six 60-ft-wide gates, a sill at el 55, and a stilling basin at el 28. The dam was designed to maintain a normal pool at el 95 upstream to Lock and Dam 4 and to pass the project flood flow of 248,600 cfs.

Purpose of Study

The general design of Lock and Dam 3 was based on sound theoretical design practice and experience with similar structures; however, navigation conditions and channel development problems are site-specific and not amenable to analytic solution. Since Lock and Dam 3 was constructed in an excavated channel bypassing a short bend, the problems were expected to be unusual especially as there were no existing flow conditions to use as a guide. Therefore, a hydraulic model study, with provisions for movable-bed operations, was necessary to determine the alignment of the channel and the arrangement of the lock and dam most satisfactory for both navigation and sediment movement. The purposes of the model study were the following:

a. To determine the adequacy of the channel alignment and the arrangement of the lock and dam.

b. To study tendency for scour and fill in the approaches to the lock and dam and determine training structures that would improve navigation conditions and minimize dredging requirements and scour problems.

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[2] All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

2 The Model

Description

A model reproducing a reach of the Red River, from 1967 river mile 143.3 to 138.9, was designed for the movable-bed experiments and built to linear scale ratios of 1:120 horizontally and 1:80 vertically (Plate 1). The upstream and downstream dimensions of the dam were constructed to the vertical scale to more nearly reproduce the dam's hydraulic characteristics. Overbank areas were molded of sand-cement mortar, and the bed was molded in crushed coal using the fixed top bank elevation as a reference. The crushed coal had a median diameter of 4 mm and a specific gravity of 1.30. Dikes were molded of crushed stone. Folded strips of wire mesh were used to simulate the roughness effects of trees and underbrush on the overbank areas. The lock and dam were fabricated of sheet metal. Dam and lock gates were simulated with simple sheet-metal slide-type gates.

The overbank portion of the model was molded to a combination of contours and elevations shown on the Red River, Louisiana, Hydrographic Survey of 1977 and the U.S. Geological Survey (USGS) quadrangle sheets dated 1960. The channel portion was molded to a hydrographic survey dated 1977. The proposed cutoff and lock and dam were installed according to plans furnished by the U.S. Army Engineer District, New Orleans.

Appurtenances

A 10-cfs axial flow pump operating in a recirculating system supplied water to the model and measured the discharge at the model's upstream end by two different sizes of venturi meters for accurate flow measurement over the range of discharges reproduced. Water-surface elevations were measured at eight model gauging stations by means of eight piezometers located in the model channel and connected to a centrally located gauge pit (Plate 1). An adjustable tailgate was provided at the downstream end of the model to control the water-surface elevation during model adjustment. During model experiments, the water-surface elevation upstream of the dam was controlled by manipulating the position of the dam gates. All gates were opened uniformly for each experiment. The tailgate at the downstream end of the model controlled the water-surface

elevation downstream of the dam. A graduated container measured the bed material introduced at the upstream end of the model. The downstream end of the model had a sediment trap installed where extruded material could accumulate and be measured at the end of any specific period. Sheet-metal templates were used for molding the model bed prior to initiation of certain experiments. A carefully graded rail was installed along each side of the channel to (a) support the templates at the correct elevations; (b) support a transverse rail used to survey the model bed; and (c) provide vertical control for installing structures in the model.

Model Adjustment

The bed and bars of movable-bed models are composed of material capable of being transported as bed load. Bank lines are normally fixed unless caving banks are expected to have a major impact on the study. Fixed bank lines and a coal bed were used in this study. Before a movable-bed model can be used to evaluate the effectiveness of proposed improvement plans, its ability to reproduce conditions similar to those expected in the prototype must be demonstrated. Complete agreement between the model and prototype is seldom obtained due to the inherent distortions incorporated in the model design and operation. Due to these dissimilarities, the degree of reliability for this model type cannot be fully established by mathematical analysis; therefore, it must be based on model adjustment. Model adjustment involves the modification of various hydraulic forces, time scale, rate of introducing bed material, and model operating techniques until the model reproduces, with acceptable accuracy, the changes known to have occurred in the prototype during a given period. Various scale relationships and model operation procedures established during model adjustment are used in examining various improvement plans. The degree of similarity between model and prototype data obtained during model adjustment is considered in the analysis of model examination data.

Conventional procedure

Normal adjustment of a movable-bed model requires two prototype bed surveys about one year apart (to provide a full range of discharges) and the stage and discharge hydrographs that occurred in the study reach between the surveys. The model bed is molded to the first prototype survey. The flows that occurred between the surveys are introduced at the upper end of the model, and the water surface at the downstream end of the model is controlled so the stages in the center of the model agree with the stages that occurred in the prototype for the period. Bed material is introduced at the upper end of the model with each flow. At the end of the period, the model bed is surveyed and the bed configurations are compared with those of the prototype survey at the end of the period. If the model does not reproduce the prototype survey closely enough, the process is repeated with modifications to the time and discharge scales, the rate of introduction of bed material, and model operating techniques. This process is repeated until the model satisfactorily reproduces the prototype bed

configurations. Once the model is adjusted, these scales and procedures are used in the study program.

Procedure for this study

Since only one recent prototype survey of the study reach was available, a conventional adjustment of the model was not possible. The prototype survey was taken in 1976 and 1977 (Plate 2) before the cutoff channels and revetments were undertaken. However, for the model study to be of value, it was essential that it be adjusted to reproduce channel configurations representative of those expected in the reach of the Red River under similar circumstances. The adjustments of the model were initiated with the model bed molded to the 1976-1977 prototype survey. The flows that occurred in the prototype year, 1 September 1976 through 31 August 1977 (Plate 3), were introduced, and the stage hydrograph in the center of the study reach at Colfax, LA, was reproduced. The initial time scale, discharge scale, rate of introducing bed material, and model operation techniques were determined from past experience with similar models within the Red River Waterway system. The resulting model bed configurations were compared with that of the 1976-1977 prototype. This procedure assumes no radical changes in the channel alignment and that the hydrograph that shaped the bed should not significantly change the bed if it is repeated. Also implicit in this method of adjustment is the requirement that discharge scales are adjusted so there is adequate bed-load transport. The amount of sediment introduced at the upstream model limits was adjusted so that the most upstream section of the model neither aggraded or degraded significantly. Progressive adjustments were made in the model scales and operating techniques following each adjustment hydrograph until a satisfactory adjustment was achieved.

Results

A comparison of the final adjustment examination results (Plate 4) with the prototype survey of 1976-1977 (Plate 2) shows that the model bed configuration generally reproduced the tendencies of the prototype. The channel at mile 141.6 and 142.1 was somewhat deeper than in the prototype, but review of the aerial photography and onsite observations indicated considerable bank line caving in this reach. Material from the bank lines would be expected to increase bed load in the area and produce a shoaling condition rather than the deepening indicated by the model. Since most of this channel was eliminated by a cutoff, it was not necessary to simulate bank caving in the area for a more accurate reproduction of the bed configuration. As a result of adjustment, the hydraulic scale relationship, the time scale, and the rate of introducing bed material were established and were used in examinations of the improvement plans.

3 Examinations and Results

Examination Procedure

After the adjustment examinations, the proposed lock and dam, closure structure, and cutoff channel were installed according to instructions from the U.S. Army Engineer District, Vicksburg. Water-surface elevations upstream of the dam were controlled to normal pool (el 95) during low flow. As the flow increased, a hinge operation was implemented to draw down the upper pool to a specific elevation depending on flow. This was done by manipulating the dam gates to obtain the desired upper pool elevation until the gates were fully open. The initial design as constructed in the model is shown in Plate 5. All plans were examined with one reproduction of the average water year hydrograph (1971-1972 hydrograph, Plate 6), and the high water year hydrograph (1958 hydrograph, Plate 7). Near the end of the examination series, some modifications were examined with the 1985 water year hydrograph (Plate 8) at the request of Vicksburg District. The tailwater stages as presented in Plates 6-8 were maintained at the downstream end of the model. Water-surface elevations downstream of the dam were controlled with a tailgate to a stage-discharge relationship curve furnished by Vicksburg District. The examination was conducted in six series. The first series was concerned with the development phase of the original design. The remaining series were a development of modifications to the original design that would (a) provide a satisfactory navigation channel width and depth with a minimum of maintenance dredging and (b) coordinate efforts with the physical model studies of the fixed-bed navigation model[1], the structural model[2], and the numerical model[3]. Prior to the first examination series for each plan and for selected modifications, the bed of the existing channel was molded to the 1976-1977 prototype survey (Plate 2), the

[1] R. T. Wooley. "Red River Waterway, Lock and Dam No. 3; Report 2, Navigation alignment conditions; Hydraulic model investigation" (in preparation), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[2] S. T. Maynord. (1991). "Red River Waterway, Lock and Dam No. 3; Report 4, Stilling basin and riprap requirements; Spillway hydraulic model investigation." Technical Report HL-91-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[3] R. R. Copeland, B. M. Comes, and W. A. Thomas. (1991). "Red River Waterway, Lock and Dam No. 3; Report 5, Sedimentation in lock approaches; TABS-2 numerical model investigation," Technical Report HL-91-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

approach channels were molded to a cross section, and the alignment was furnished by the Vicksburg District. Examinations of the remaining modifications were initiated with the model bed configurations that existed at the end of the previous examination. The model bed was surveyed following each hydrograph repetition, and prior to some examinations, a navigation channel was dredged in specific reaches.

Most of the plan modifications were developed during preliminary examinations. Promising modifications were incorporated into more comprehensive plans. Results of the preliminary examinations were furnished to the Vicksburg District but are not included in this report.

Original Design

Description

Immediately after the model was verified, the lock and dam were placed in the cutoff channel in the configuration and design specified by the Vicksburg District. The original design, as installed in the model, is shown in Plate 5. The 1971-1972 average water year hydrograph was reproduced. The upper pool was maintained using "hinge pool" operation, which involves changing the normal upper pool elevation in relation to changing river discharge. The upper pool elevation to be maintained for the specified river discharge is as follows:

River Discharge, cfs	Upper Pool El
less than 60,000	95.0
60,000	94.0
70,000	92.0
80,000	88.0
90,000	89.0
100,000	89.0
120,000	89.0
greater than 120,000	uncontrolled

A total of 29 repetitions of the average water year hydrograph were reproduced until the model reached stability (where the quantity of bed material extruded from the model was equivalent to that being input per hydrograph).

Results

The survey taken after the final run with the originally installed lock and dam design shows that the upper pool filled considerably but not enough to limit navigation (Plate 9). The lower lock approach shoaled to within a few feet of the lower pool elevation, and there is a large shoaled area at the intersection of the old and new channels below the lock that would impede navigation in all but the highest lower pool stages.

Plan A

Description

Plan A was based on the preliminary examinations completed on the physical navigation model.[1] Plan A modified the originally installed plan by installing a series of spur and L-head dikes in the upper pool upstream of the confluence of the old channel and the cutoff channel for the lock and dam, moving the right bank line upstream of the dam from 2,000 to 7,700 ft upstream of the axis of the dam riverward, modifying the left bank line of the upper pool by extending it further upstream, and adding a trail dike off the downstream end of the lock (Plate 10). A total of 150 modifications were made on the movable-bed model including various dike and bank line configurations in an attempt to reduce shoaling in both the upper pool and in the lower lock approach.

Results

The Plan A-150, Run 10 (Plate 11), survey shows that the upper pool, especially along the right bank line near the upstream limit of the model, was shoaling above the navigation channel depth. In the lower pool, there was shoaling along the channel side of the lock. The channel below the dam shoaled to near the navigation channel depth but still maintained adequate depth. There was a large scour approximately 1,000 ft downstream of the trailing dike along the left bank line and in the lower lock approach. This scour was due to a strong eddy in the lower lock approach and would likely be unacceptable for navigation conditions. There was also considerable shoaling between and channelward of the first two right bank vane dikes near mile 139.5, and this shoal encroached on the available navigation channel width in that portion of the channel.

[1] R. T. Wooley, op. cit.

Plan B

Description

Plan B used the same bank line and dike configuration as Plan A-150 except that the dam was moved toward the lock by 60 ft (Plate 12). Plan B was examined with seven repetitions of the average water-year hydrograph.

Results

The survey taken at the end of Plan B, Run 7 (Plate 13), showed that the upper pool, especially along the right bank at the upper end of the model, continued to aggrade. Moving the dam adjacent to the lock eliminated the shoaling along the lock seen with Plan A-150. The scour along the left descending bank in the lower lock approach enlarged and deepened slightly, still indicating that the strong eddy was not affected. Shoaling between and channelward of the first two right bank vane dikes near mile 139.5 continued to encroach on the navigation channel.

Plan C

Description

Plan C modified Plan B by installing a powerhouse structure on the right side of the dam and modifying the right bank revetments immediately upstream and downstream of the powerhouse. The plan as installed in the model is shown in Plate 14. A total of four repetitions of the average water year hydrograph were performed with this plan.

Results

The survey taken after completion of Plan C, Run 4 (Plate 15), showed that shoaling was similar to what had occurred with Plan B, Run 7 (Plate 13). There was a shoal immediately downstream of the dam. The scour along the left bank approximately 1,000 ft below the trailing dike off the downstream guard wall remained similar to Plan B, indicating the eddy was unaffected by the flow patterns of the added powerhouse. Shoaling between and channelward of the right bank vane dikes approximately 7,000 ft downstream of the dam continued to encroach on the available channel width.

Plan C-1

Description

Plan C-1 was the same as Plan C except for a solid wall 890 ft long at el 95, extending upstream perpendicular to the axis of the dam between the dam and the powerhouse, to limit the amount of sediment being pulled into the powerhouse. This plan is shown in Plate 16.

Results

The survey taken after completion of Plan C-1, Run 4 (Plate 17), showed little change in the shoaling in the upper pool compared with Plan C, Run 4 (Plate 15). The 890-ft wall reduced, but did not eliminate, sediment moving into the powerhouse. The shoal immediately downstream of the dam enlarged compared with Plan C results. The large scour on the left bank about 1,000 ft downstream of the trailing dike on the downstream guard wall remained about the same as with Plan C. Shoaling adjacent to the vane dikes near the downstream end of the model also continued.

Plan D

Description

During operation of Plan C-1, the Vicksburg District requested that the revetments below the lock and dam be realigned. After completion of Plan C-1, these modifications were made to the model and the new plan was designated Plan D. The changes made for Plan D were as follows:

a. Removal of the powerhouse structure.

b. Addition of a submerged berm along the left bank in the upstream lock approach to el 73 extending upstream 3,100 ft from the axis of the dam.

c. Modification of the right bank revetment immediately upstream and downstream of the dam to reflect the removal of the powerhouse.

d. Realignment of left and right bank revetments starting at 2,500 ft downstream of the axis of the dam, toward the left, creating a straight channel from the downstream lock approach to the downstream end of the model.

e. Shortening the downstream portion of the right bank revetment downstream of the dam by 500 ft.

f. Removal of the five right bank vane dikes near the downstream end of the model and installation of six vane dikes, the most upstream dike being 350 ft long, the others 300 ft, and all being 700 ft apart, along the new channel alignment beginning at 6,550 ft downstream of the axis of the dam.

The plan as installed in the model is shown in Plate 18. A total of two modifications were made to Plan D.

Results

The survey taken after completion of Plan D-2, Run 3 (Plate 19), showed continued shoaling along the right bank at the upstream end of the model. Most of the upper pool remained about the same as that of Plan C-1. There was some slight shoaling in the upper lock approach near the upstream end of the upper guard wall and considerable shoaling along the lock below the dam. The scour along the left bank at 1,000 ft downstream of the trailing dike of the lower guard wall was somewhat less than with previous plans. However, with Plan D-2, shoaling occurred along the right bank adjacent to that scour. Shoaling along the left bank near the downstream confluence with the old channel was also noted. There was considerable shoaling between and channelward of the right bank vane dikes near the downstream end of the model with some encroachment on the navigation channel along the two most downstream dikes.

Plan E

Description

Plan E as installed in the model added modifications that were developed in the fixed-bed navigation model. The modifications made to the Plan D-2 design included the following:

a. Installation of four vane dikes along the right bank beginning at 7,000 ft upstream of the axis of the dam and ending at 10,550 ft upstream of the dam, all being 500 ft long and spaced 1,000 ft apart.

b. Extension of the left bank upstream berm from 3,100 ft upstream of the dam to 4,800 ft upstream of the dam at el 64, transitioning from el 73 at 3,100 ft upstream of the dam to el 64 at 3,400 ft upstream of the dam.

c. Modification of the right bank revetment in the upper pool, moving it riverward approximately 50 ft.

The channel bed upstream of the dam was el 64. The installed plan is shown in Plate 20. A total of 17 repetitions of the average water-year hydrograph were reproduced with this plan.

Results

The survey taken after completion of Plan E, Run 17 (Plate 21), showed that the channel through the upstream vane dike field remained slightly deeper than with Plan D-2 (Plate 19). There was considerable shoaling on the upstream left bank berm from the upstream end into the upper lock approach adjacent to the guard wall; however, this shoal did not limit navigation depth. There was a shoal along the downstream lock wall where the downstream guard wall attaches. The channel along the left bank in the lower lock approach opposite the trailing dike shoaled above the minimum navigation depth. The scour along the left bank approximately 1,000 ft downstream of the trailing dike remained, and again there was some shoaling along the right bank line opposite this scour. The channel along the downstream right bank vane dikes continued to shoal along the channel side of the dikes and also on the left bank opposite the third most downstream dike.

Plan E Modified

Description

Plan E Modified used the same lower pool bank line and dike configuration as Plan E. The changes made in the upper pool compared with Plan E are as follows:

a. Removed the upstream left bank berm from 4,800 ft upstream of the axis of the dam into the upper lock approach. This made the area upstream and into the lock approach and the approach to the dam at a constant elevation of 64.

b. Added a right bank spur dike 6,550 ft upstream of the axis of the dam to el 97.

c. Modified the right bank revetments from 6,500 ft upstream of the axis of the dam to the dam, with the main feature being the addition of an underwater berm, 175 ft in width at el 78 along the right bank.

The plan as installed in the model is shown in Plate 22. The model was operated for five repetitions of the average water year hydrograph. The Vicksburg District then requested that the 1982-1983 hydrograph (Plate 23) (stage measured at the downstream end of the model), a hydrograph determined to be more representative of the design discharge duration curve, be operated for several repetitions to forecast possible sediment-related problems on startup of the project with this plan. These examinations were designated as T-0, with T-0 being initial startup after the project was put into operation. The model was first remolded, then a total of five repetitions of the 1982-1983 hydrograph were performed.

Results

The survey taken after Plan E Modified, Run 5, of the average water year hydrograph (Plate 24) showed the upper pool to have almost no shoaling problems except for considerable shoaling at the extreme upstream end of the model along the left bank. The lower pool showed deposition alongside the lock and at the junction of the lock and downstream guard wall. Also, there was shoaling along the left bank inside the lower lock approach opposite the guard wall, and scouring along the left bank 1,000 ft downstream of the trailing dike remained, along with shoaling along the right bank opposite the scour. There was considerable deposition along the left bank near the downstream confluence with the old channel and along the right bank side through the vane dike field.

The survey taken after completion of Plan E Modified, T-0, Run 5 (Plate 25), using the 1982-1983 hydrograph, showed almost no appreciable deposition in the upper pool except for a shoal at the extreme upstream end of the model along the left bank. The lower pool continued to indicate deposition alongside the lock and at the junction of the lock and downstream guide wall. There was a large shoal along the left bank just downstream of the lower guard wall and immediately upstream of the large left bank scour. Shoaling continued on the right bank opposite this large scour. The channel through the vane dike field near the downstream end of the model continued to aggrade with a large reduction of channel width near the extreme downstream end of the model.

Plan F

Description

Plan F was the same as Plan E Modified except for the following:

a. A 474-ft-wide opening through the upstream left bank revetment at el 73 centered at approximately 4,600 ft upstream of the axis of the dam for an entrance into a central maintenance facility in the old channel was added.

b. The downstream right bank revetment was moved toward the right, widening the downstream approach channel from 250 ft to 350 ft.

c. The six right bank vane dikes downstream of the dam were moved toward the right bank to provide a 500-ft-wide channel, as measured from the toe of the left and right bank revetments, through the dike field.

The plan as installed in the model is shown in Plate 26. A total of ten repetitions of the 1982-1983 hydrograph were conducted with this plan.

Results

The survey taken after completion of Plan F, Run 10 (Plate 27), showed no indication of shoaling problems in the upper pool. In the lower pool, there was deposition at the junction of the lock and guard wall. There was a large shoal along the left bank in the lower lock approach immediately downstream of the trailing dike off the downstream guard wall. The scour that had been seen along the left bank approximately 1,000 ft below the trailing dike in previous surveys was relocated along the right bank directly opposite its previous location. The channel completely shoaled starting just upstream of the lower confluence with the old channel and extending the length of the confluence until reaching the second vane dike downstream of the dam. There was also considerable shoaling along the left bank opposite the third and fourth vane dikes, on the right bank off the ends, and between the fifth and sixth vane dikes downstream of the dam.

Plan G

Description

After completion of Plan F examinations, operation of the movable-bed model was suspended for approximately one year. Upon reactivation, Plan G, based on the fixed-bed navigation model results of Plan I-3 in the upper pool and Plan H-5 in the lower pool, was installed in the movable-bed model. The modifications for Plan G were as follows:

a. The left and right bank lines in the upper pool were realigned to allow the bank to follow its natural path to the upstream confluence, then the left bank shifted. Also the right bank was shifted landward, providing a 500-ft-width channel from the toe of the revetments on both side of the channel starting 4,900 ft upstream of the dam.

b. The downstream right bank revetment and six downstream vane dikes were modified to match Plan E Modified, except for changes in the right bank revetment immediately downstream of the dam that transitioned from the width at the dam to the navigation channel width downstream of the lock.

c. The downstream left bank revetment was realigned parallel to the right bank revetment and provided a constant 300-ft width between the toe of the slopes from 2,500 ft downstream of the axis of the dam to the downstream end of the model.

The plan as installed in the model is shown in Plate 28. Experiments to be performed in the movable-bed model were to determine shoaling tendencies with this plan after it was put into operation after completion of the project. This is designated as T-0, with T-0 being the project at completion of construction. Seven repetitions of the average water year hydrograph were performed, then

one repetition of the high water year hydrograph (Plate 7), then three more repetitions of the average water year hydrograph.

Results

The survey taken after completion of Plan G, Run 7 (Plate 29), showed the upper pool indicated no evidence of significant shoaling. Downstream of the dam, there was a large shoal at the junction of the lock and the guard wall. There was some shoaling along the edges of the left and right banks from the lower lock approach to the downstream end of the model, but nothing of significance. The scour that had been seen through previous model evaluations about 1,000 ft downstream of the trailing dike off the end of the downstream guard wall was eliminated.

The survey taken after completion of Plan G, Run 8 (Plate 30), using the 1958 high water hydrograph, showed some aggradation in the upper pool compared with Plan G, Run 7. The lower pool showed a complete shoal across the width of the channel from the junction of the lock and the downstream guard wall to the right bank. There was a shoal completely across the channel at approximately 3,000 ft downstream of the dam and again at approximately 6,000 ft downstream of the dam. There was considerable shoaling between the downstream vane dikes and some shoaling along the channel ends of the dikes, encroaching on the navigation channel.

The survey taken after completion of Plan G, Run 11 (Plate 31), showed little change in the upper pool compared with Plan G, Run 8 (Plate 30), indicating little if any aggradation. Downstream of the dam, the shoals as described for Plan G, Run 8, remained, but were somewhat reduced in size. This indicates that the average water year hydrograph was slowly degrading these shoal areas. The channel through the downstream vane dike field remained about the same as with Plan G, Run 8.

4 CONCLUSIONS

Model Limitations

The limitations of this model are based on the presumption that the major portion of sediment deposited in this system is bed load. The Red River has a heavy concentration of fine material that remains suspended within the water column when current velocities remain high enough. In areas of slack or very slowly moving water, this material tends to drop out.

The movable-bed model used for this study was designed to look specifically at bed-load material. The model was not and could not be used to address the problems associated with suspended load and how it might affect the design of the structures and channel contraction works. Even with this limitation, the model study was considered to be adequate to successfully evaluate the proposed lock and dam design and to develop revetments and contraction works to minimize deposition within the navigation channel.

Model Conclusions

Conclusions reached from the results of the model study are as follows:

a. *Plan A.* This plan would not adequately maintain the navigation channel downstream of the dam.

b. *Plan B.* This plan, which moved the dam adjacent to the lock, would not maintain an adequate navigation channel in the extreme upper pool or downstream of the dam.

c. *Plan C.* This plan had the powerhouse in place, and although no worse than Plan B without the powerhouse, would not maintain an adequate navigation channel in the extreme upper pool or downstream of the dam.

d. *Plan C-1.* This plan added a solid wall between the powerhouse and the dam, eliminating some of the sediment moving through the powerhouse, but still did not maintain an adequate navigation channel.

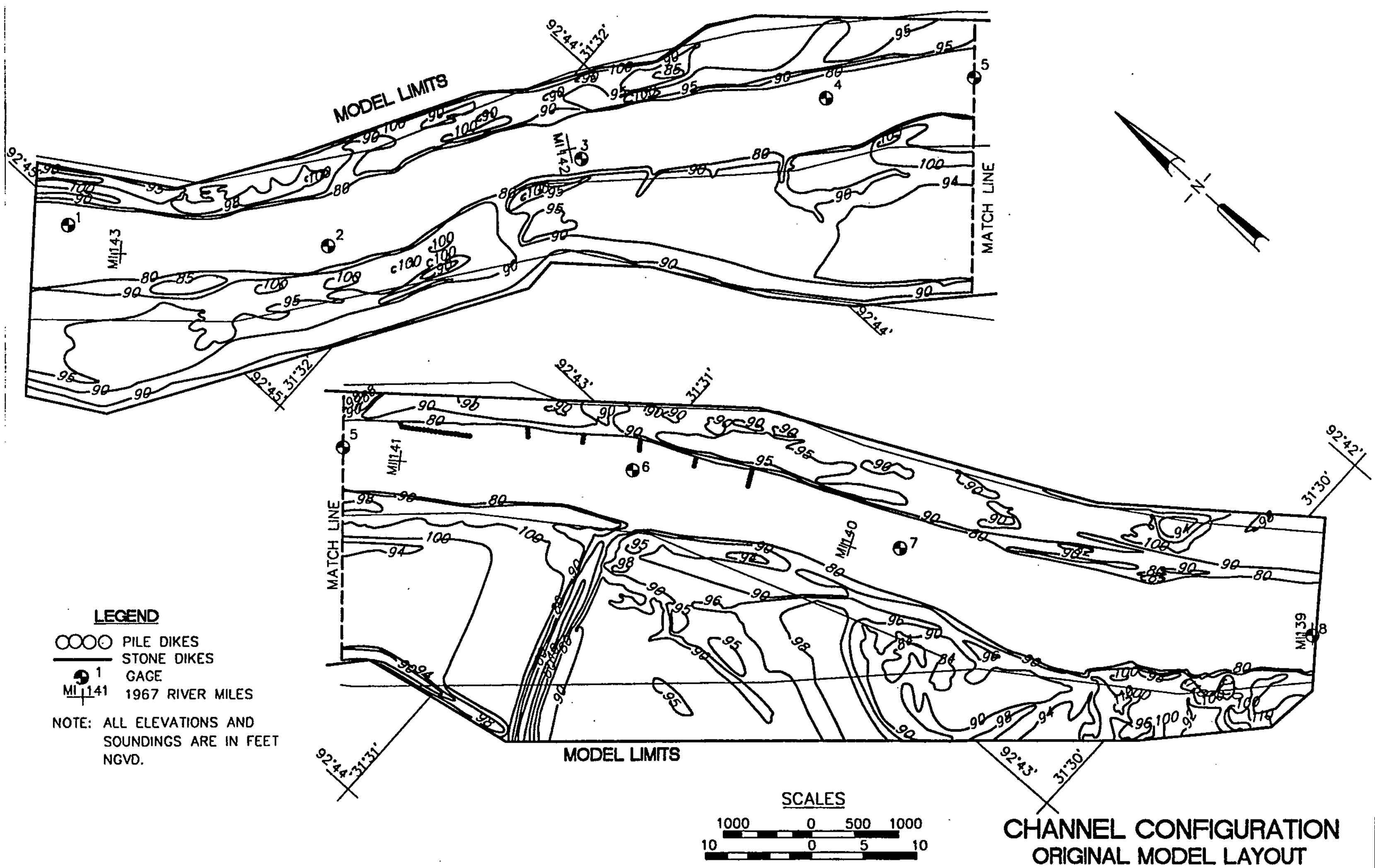
e. *Plan D.* This plan, using the realigned revetments downstream of the dam, would not maintain an adequate navigation channel in either the upper pool or in the lower pool downstream of the lock.

f. *Plan E.* This plan, using modifications developed in the fixed-bed navigation model, improved the shoaling conditions in the upper pool but did not maintain an adequate navigation channel in the lower pool.

g. *Plan E Modified.* This plan removed the upstream left bank berm and added an upstream right bank berm, which almost eliminated shoaling in the upper pool except at the extreme upstream end of the model. However, it did not maintain an adequate navigation channel in the lower pool.

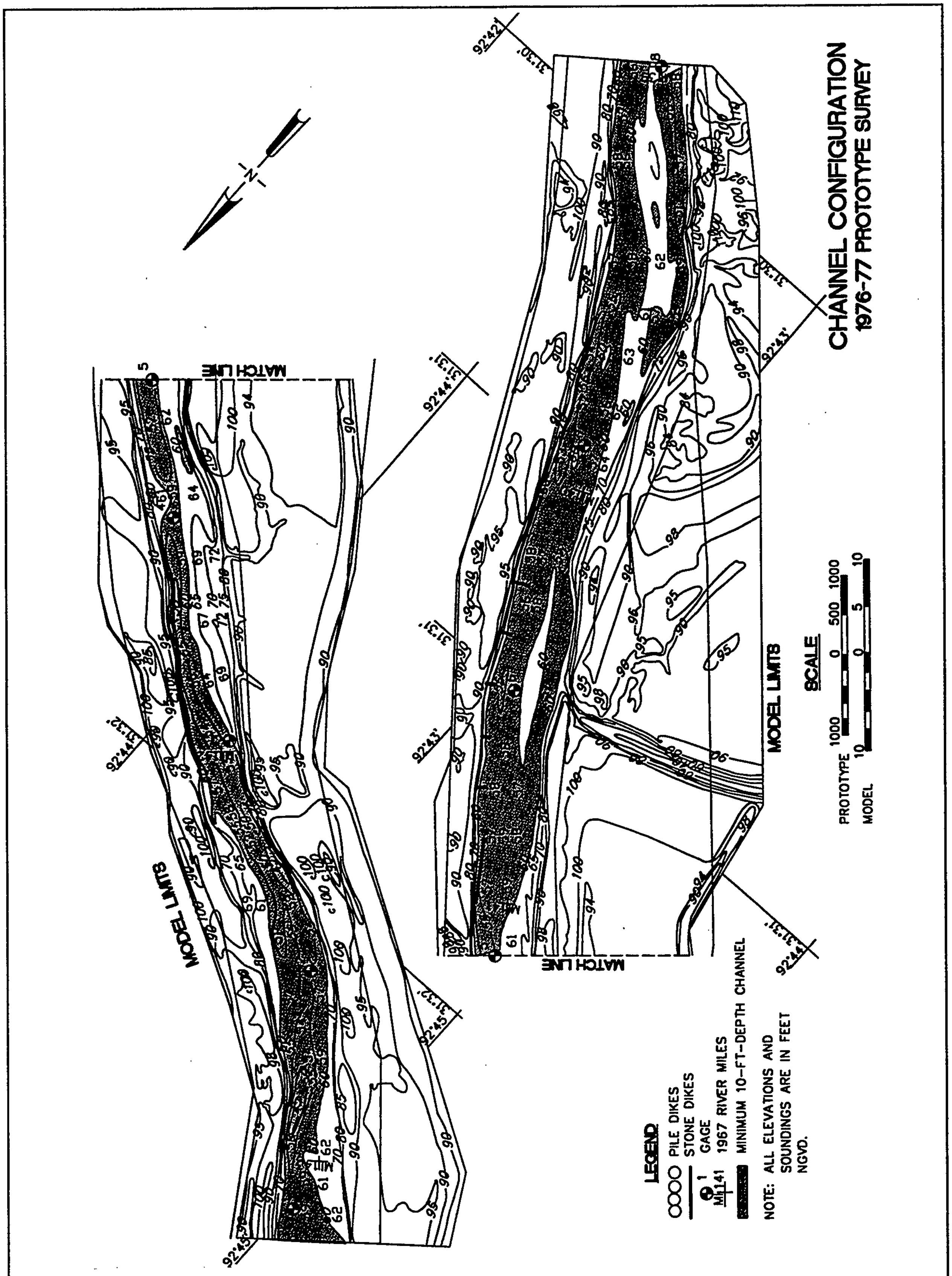
h. *Plan F.* This plan, adding an opening through the upstream left bank revetment and modifying the downstream right bank revetment and vane dikes, maintained the upper pool with no apparent shoaling but did not maintain an adequate navigation channel in the lower pool.

i. *Plan G.* This plan, installing modifications developed in the fixed-bed navigation model for Plans I-3 in the upper pool and H-5 in the lower pool, maintained the navigation channel in the upper and lower pools with operation of the average water year hydrograph. Operation of the 1958 high water year hydrograph produced shoaling in the lower pool that would impede navigation; however, operation of the average water year hydrograph immediately following the high water year hydrograph without dredging the channel produced gradual improvement of the shoaled areas.



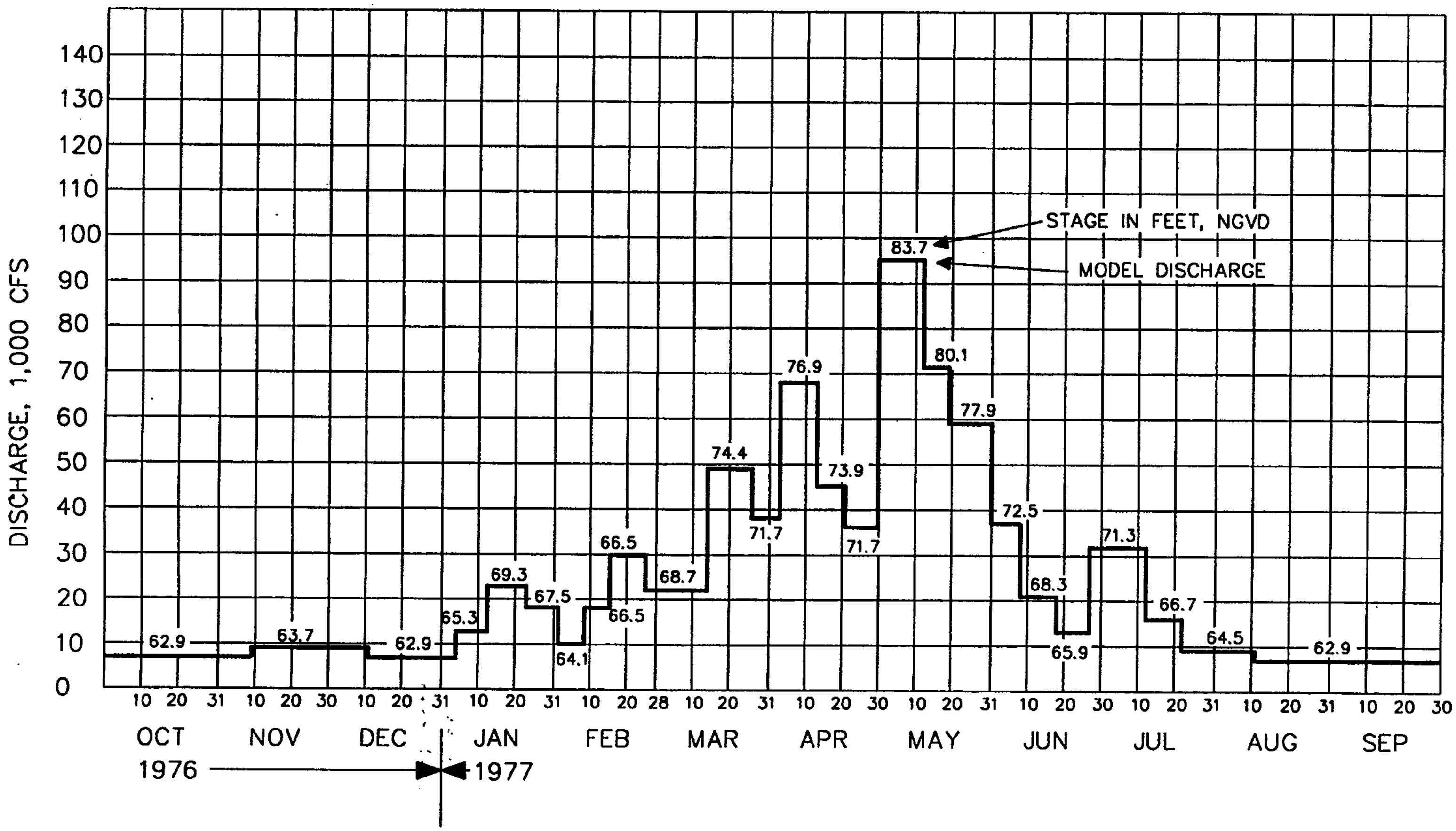
CHANNEL CONFIGURATION
ORIGINAL MODEL LAYOUT

Plate 1

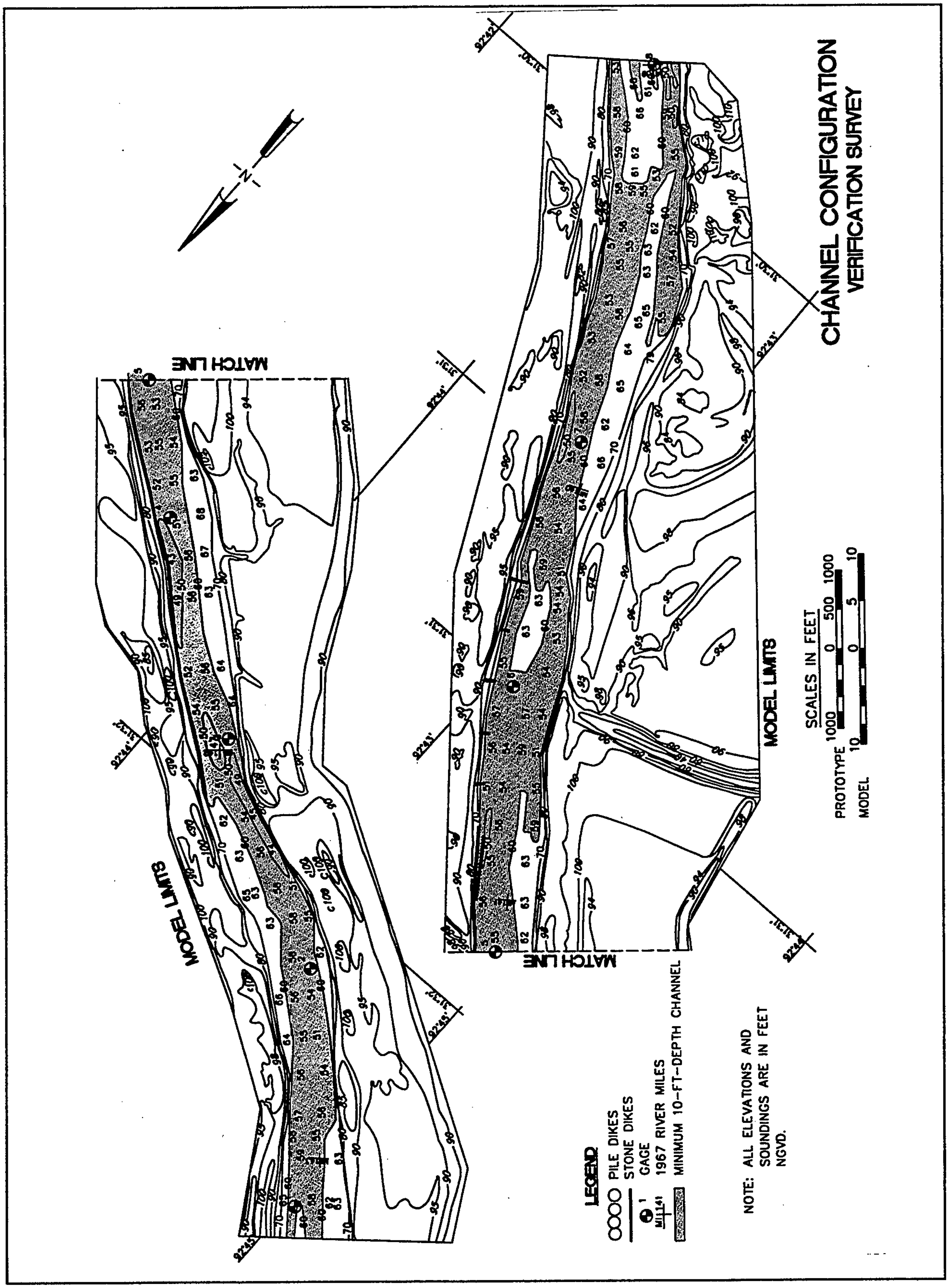


CHANNEL CONFIGURATION
1976-77 PROTOTYPE SURVEY
MODEL LIMITS
MATCH LINE
LEGEND
PILE DIKES
STONE DIKES
GAGE
1967 RIVER MILES
MINIMUM 10-FT-DEPTH CHANNEL
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.
SCALE
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10

Plate 2

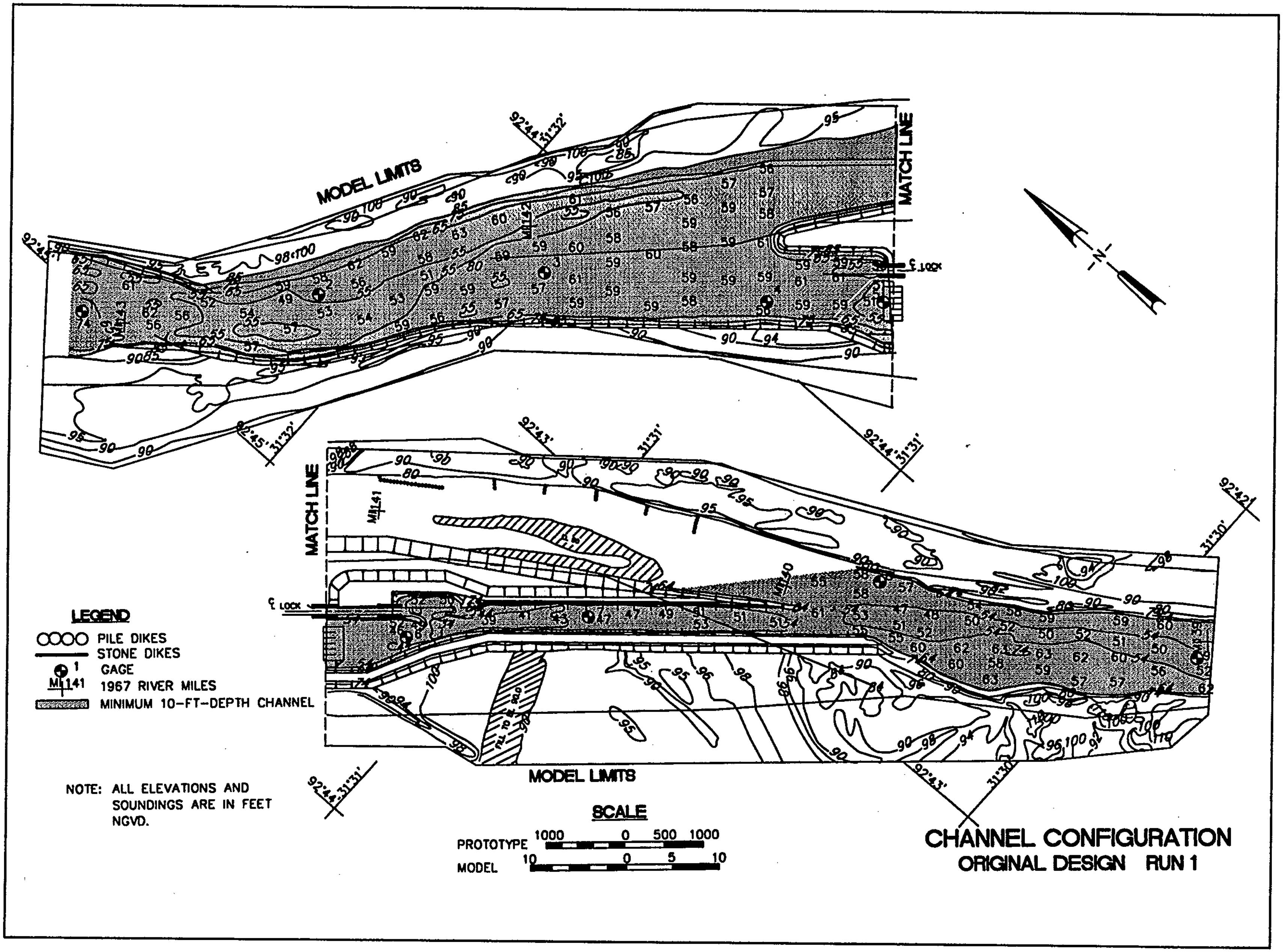


1976-1977 HYDROGRAPH



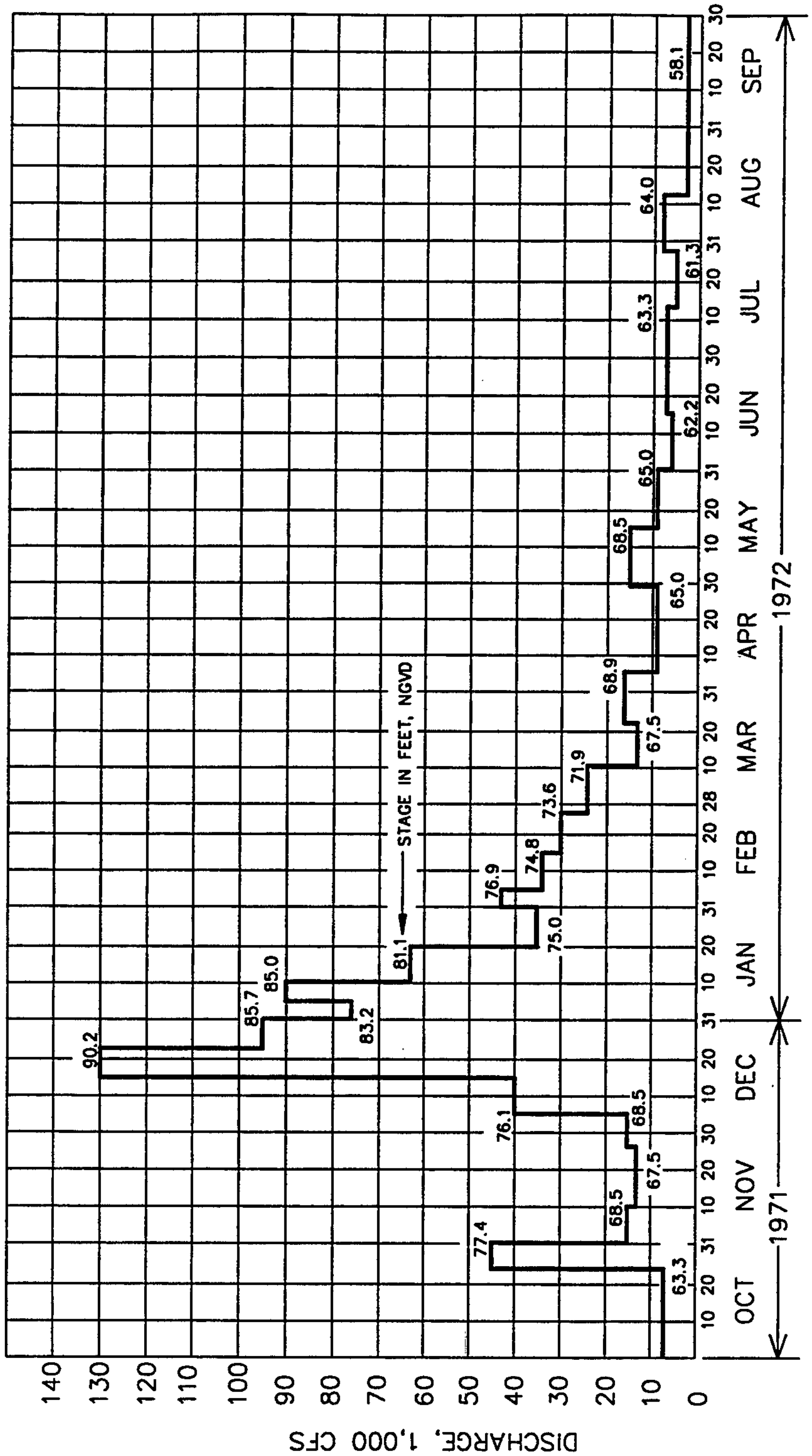
CHANNEL CONFIGURATION
VERIFICATION SURVEY
N
MODEL LIMITS
MATCH LINE
MATCH LINE
MODEL LIMITS
SCALES IN FEET
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10
LEGEND
PILE DIKES
STONE DIKES
GAGE
1967 RIVER MILES
MINIMUM 10-FT-DEPTH CHANNEL
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.

Plate 4



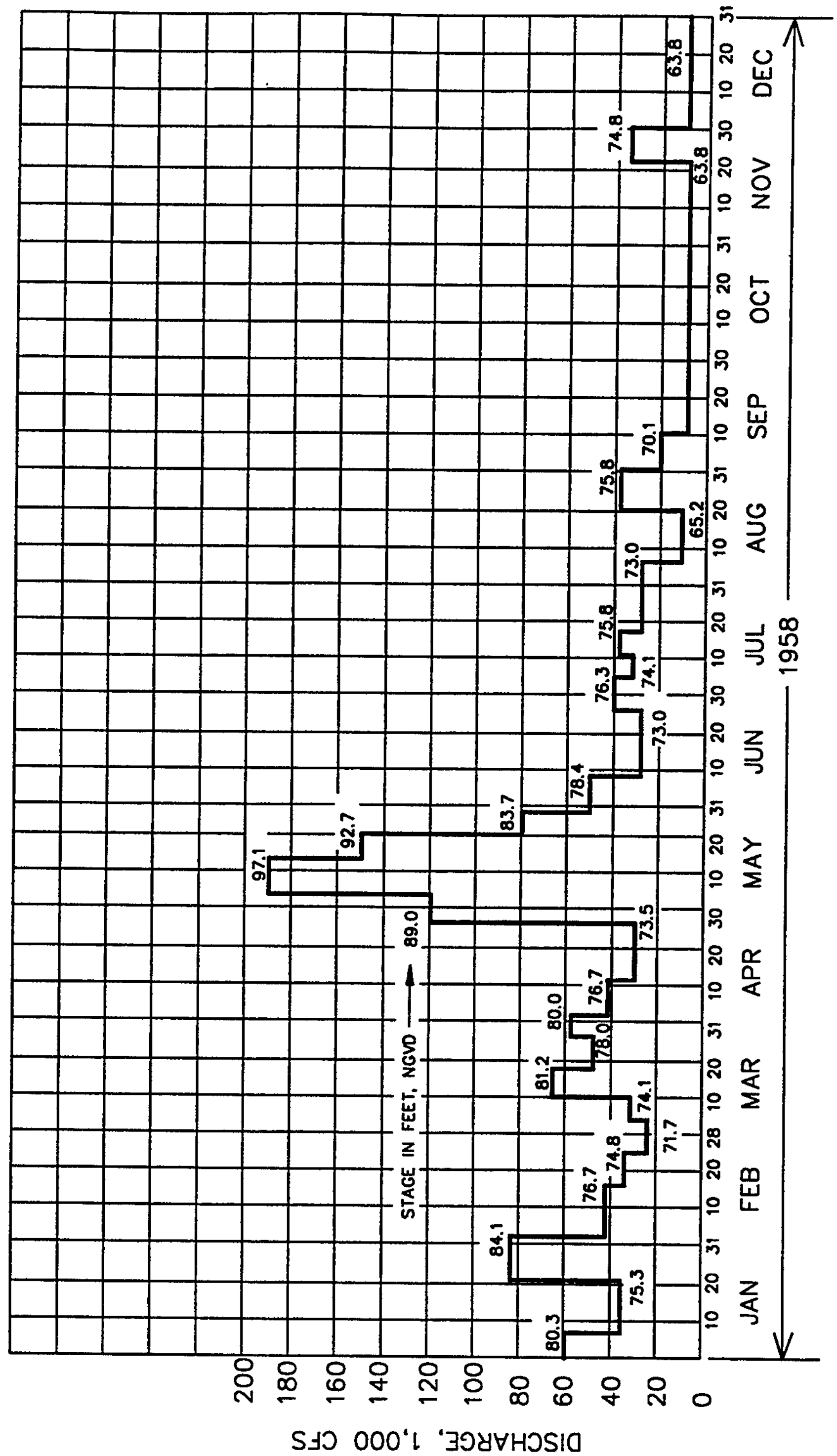
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.

CHANNEL CONFIGURATION
ORIGINAL DESIGN RUN 1



AVERAGE WATER HYDROGRAPH

Plate 6



HIGH WATER HYDROGRAPH

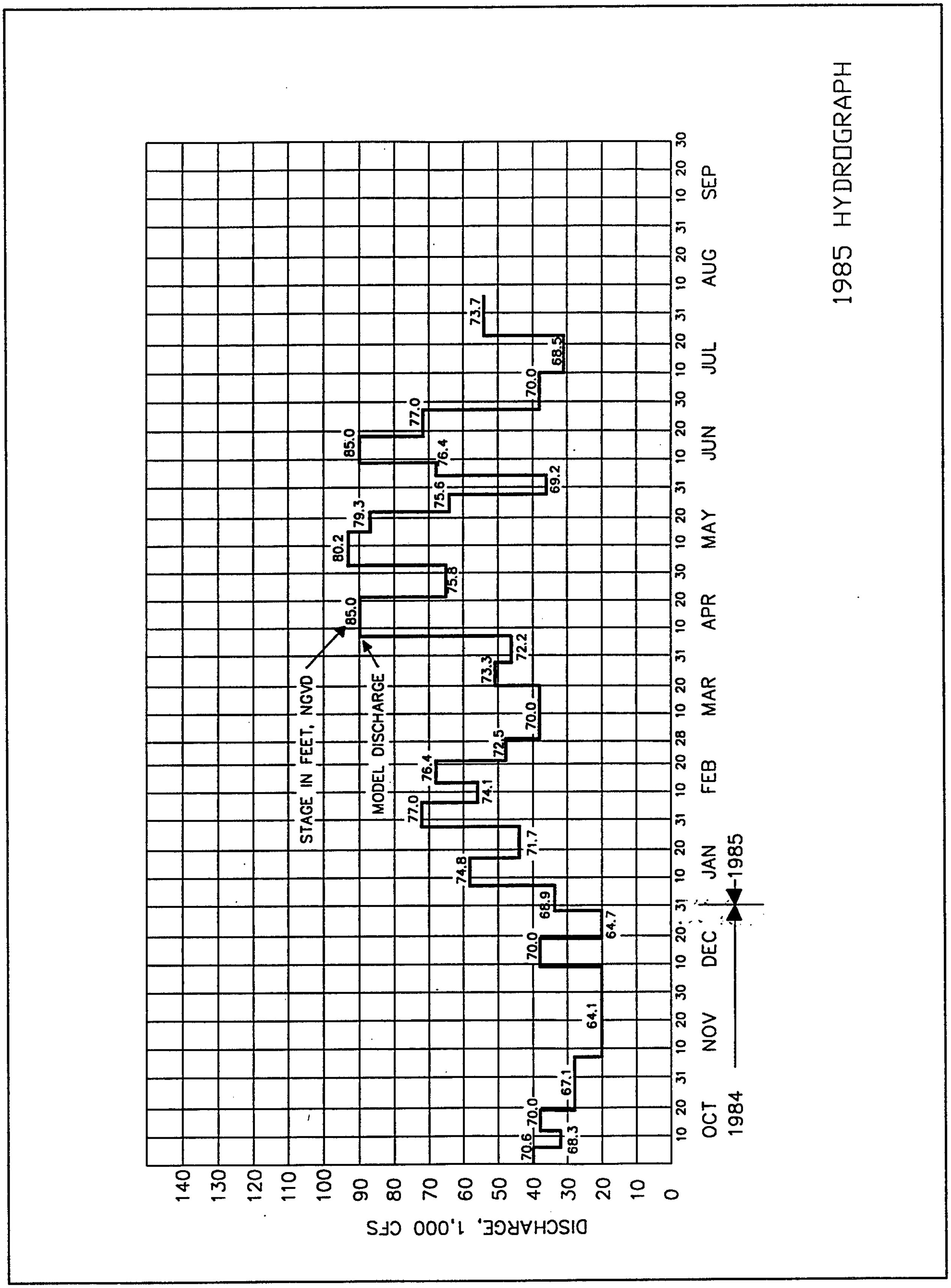
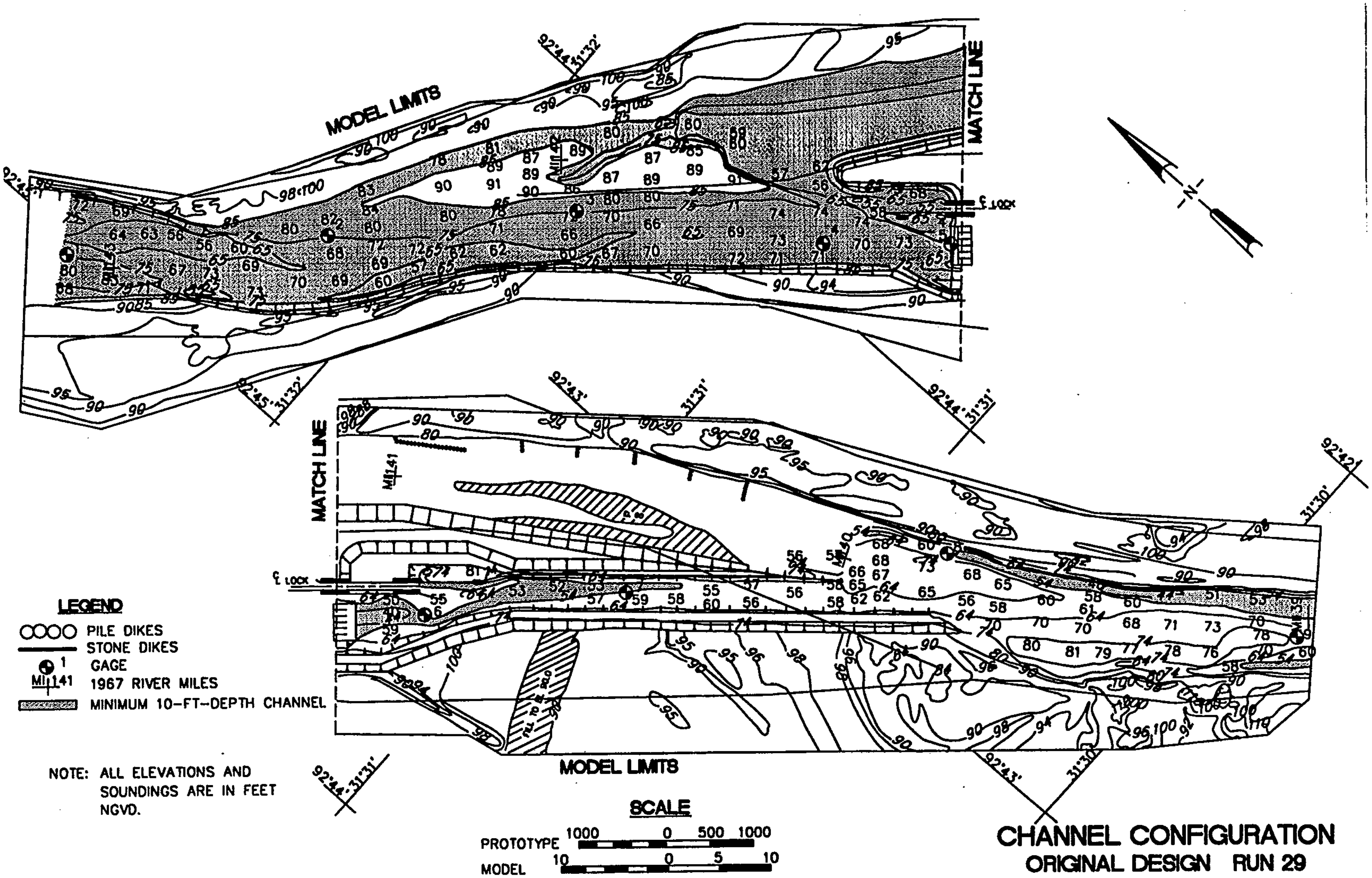

1985 HYDROGRAPH
DISCHARGE, 1,000 CFS
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
1984
1985
STAGE IN FEET, NGVD
MODEL DISCHARGE
70.6
68.3
70.0
67.1
64.1
70.0
64.7
68.9
74.8
71.7
77.0
74.1
76.4
72.5
70.0
73.3
72.2
85.0
75.8
80.2
79.3
75.6
69.2
76.4
85.0
77.0
70.0
68.5
73.7

Plate 8

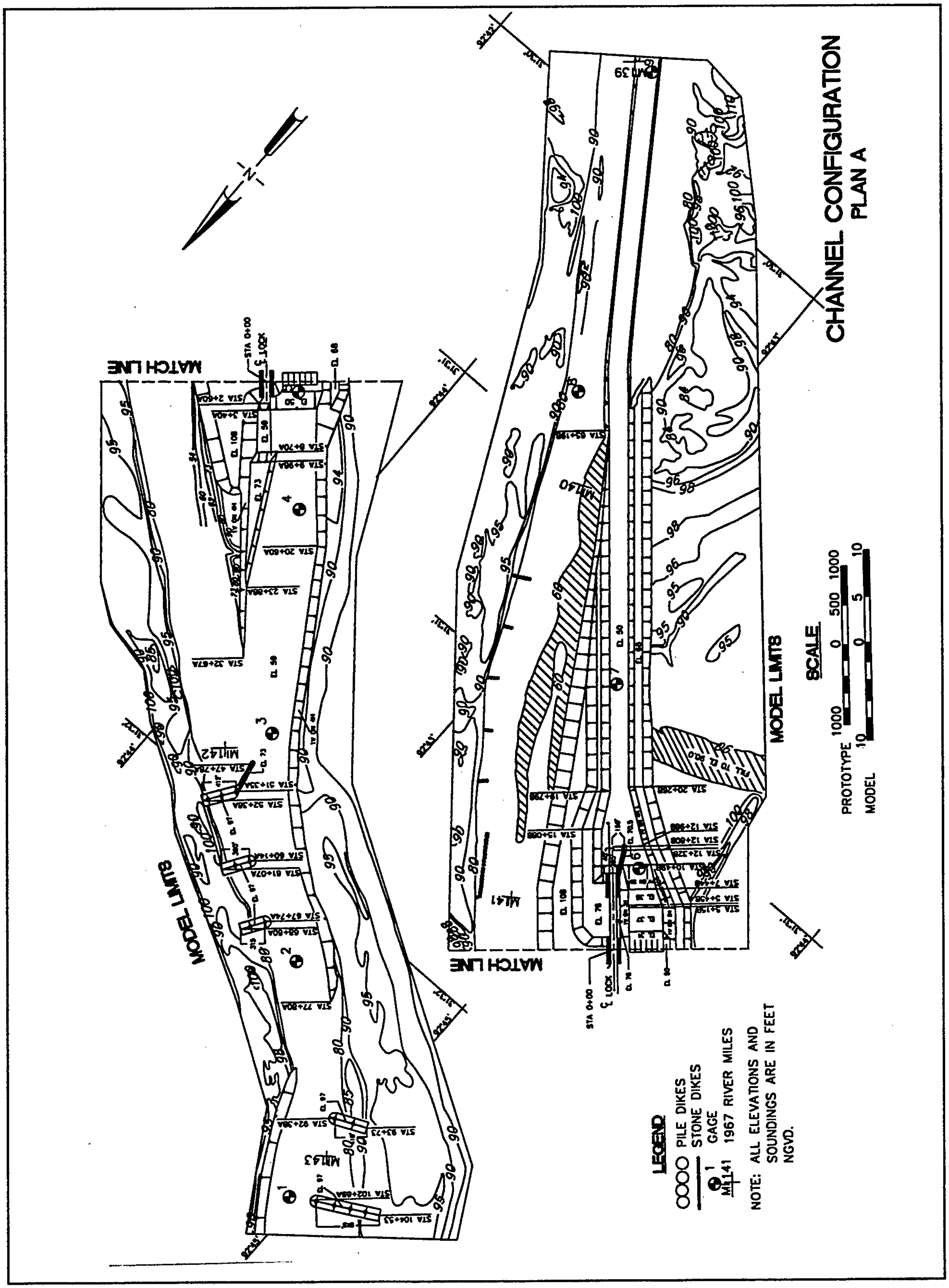


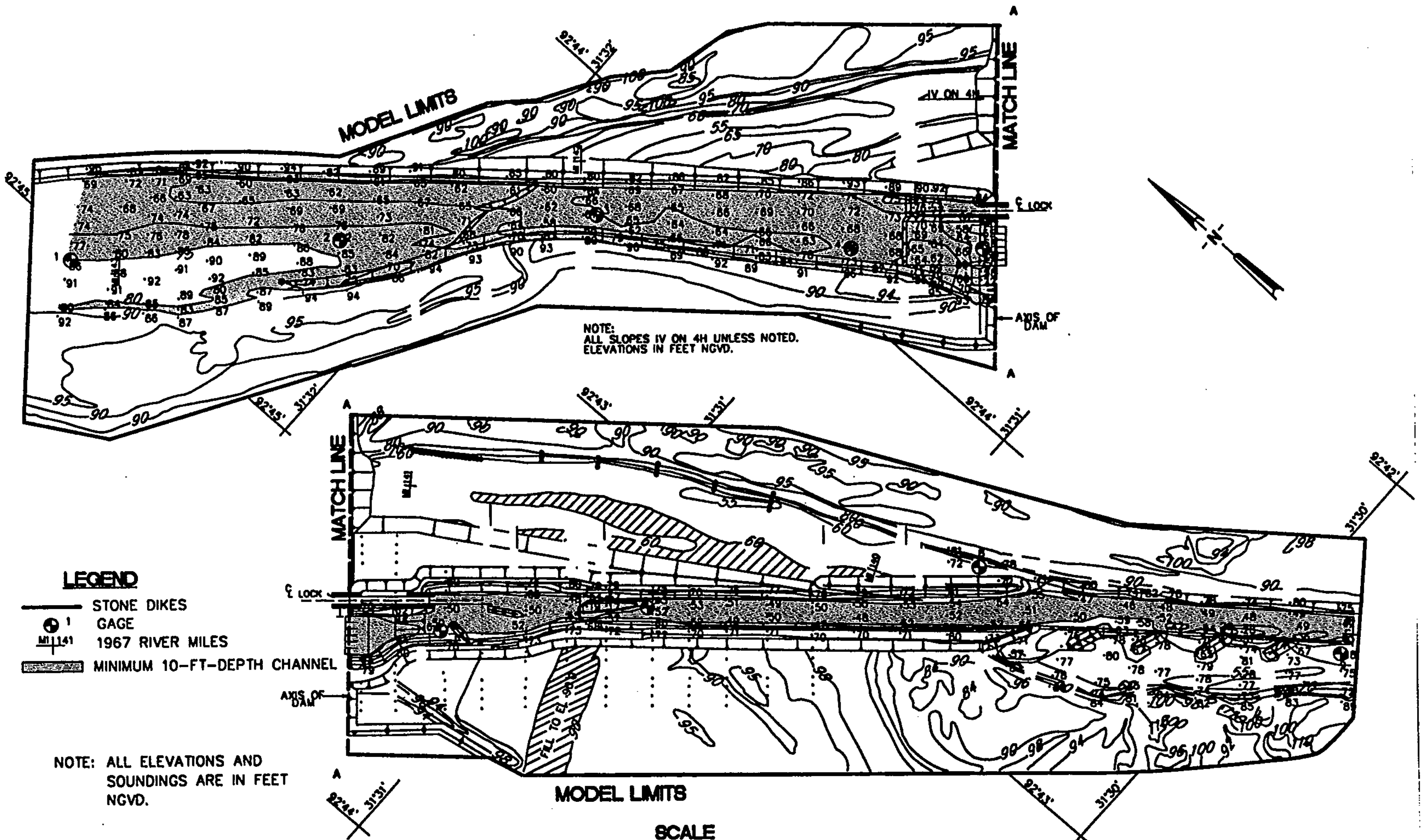
LEGEND

- PILE DIKES
- STONE DIKES
- 1 GAGE
- MI 141 1967 RIVER MILES
- MINIMUM 10-FT-DEPTH CHANNEL

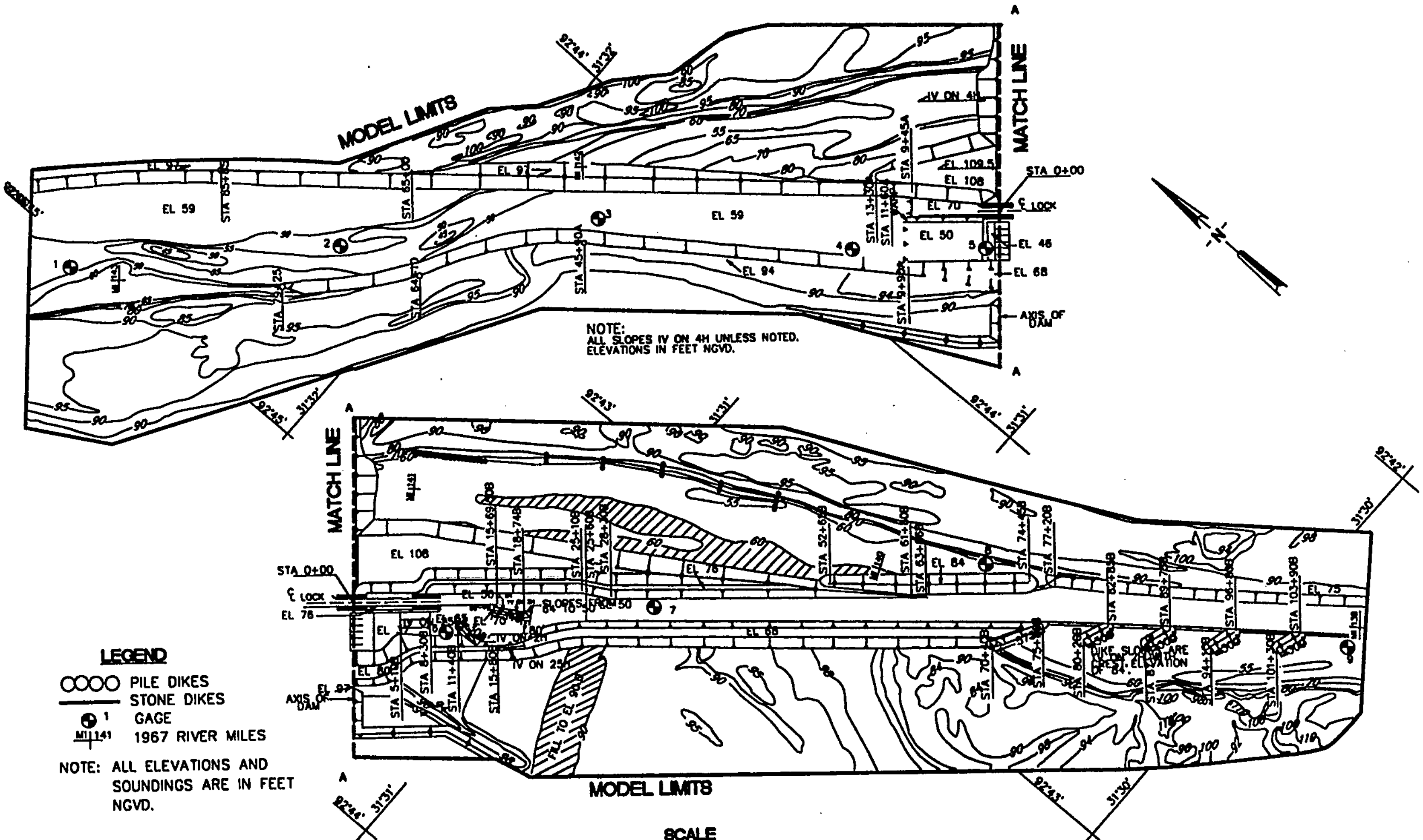
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.

CHANNEL CONFIGURATION
ORIGINAL DESIGN RUN 29

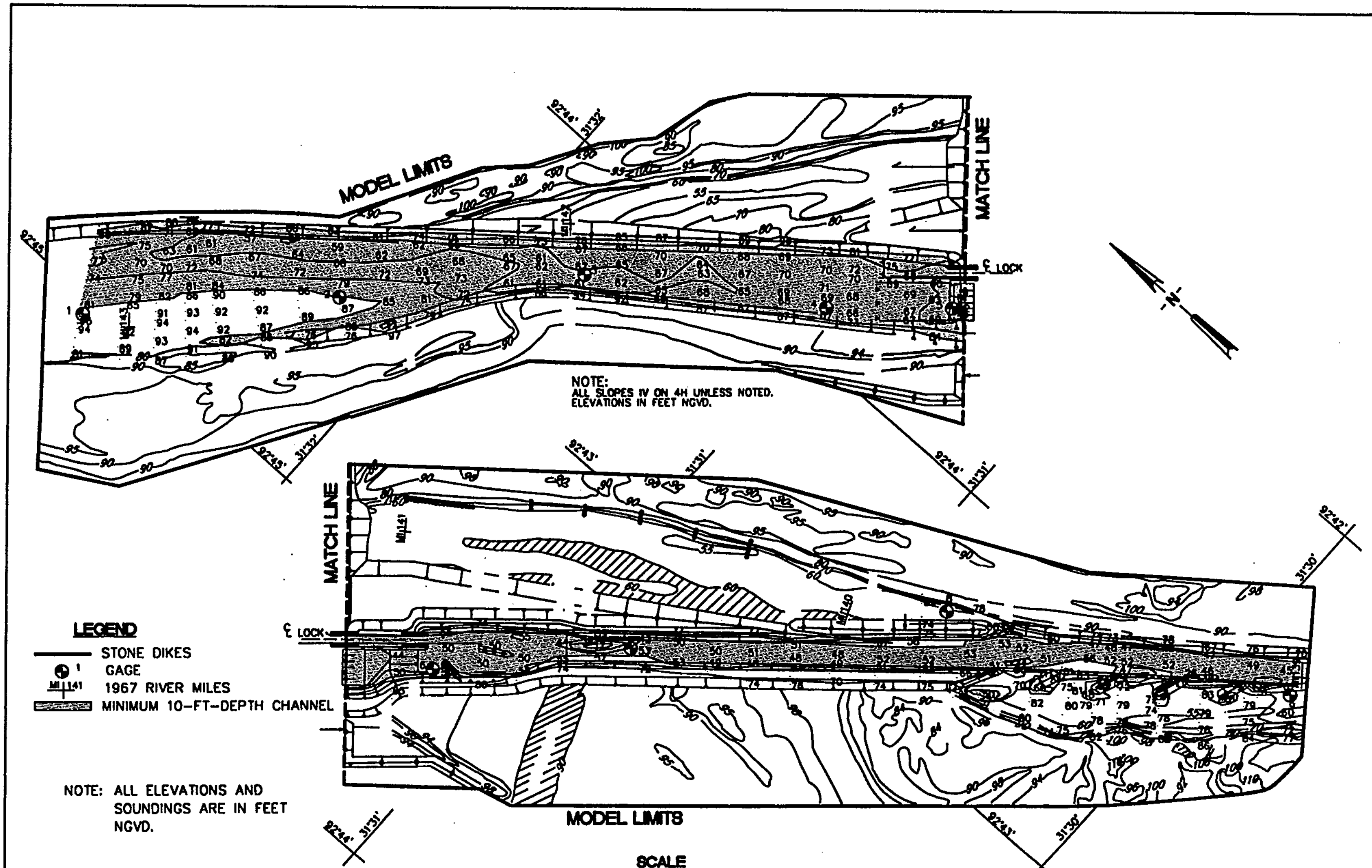

CHANNEL CONFIGURATION
PLAN A
LEGEND
PILE DIKES
STONE DIKES
GAGE
1967 RIVER MILES
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.
SCALE
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10
MODEL LIMITS
MATCH LINE



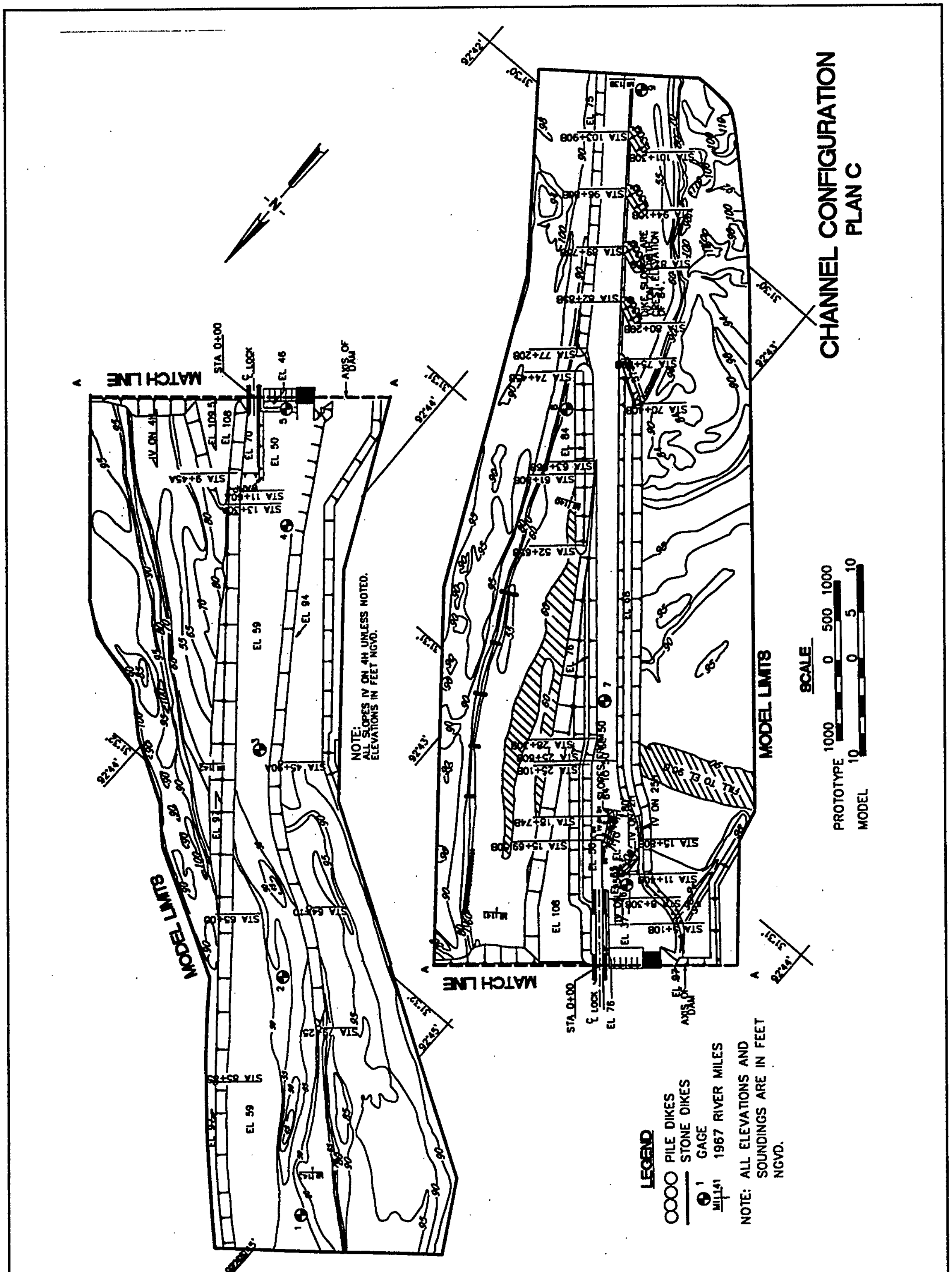
CHANNEL CONFIGURATION
PLAN A-150 RUN 10

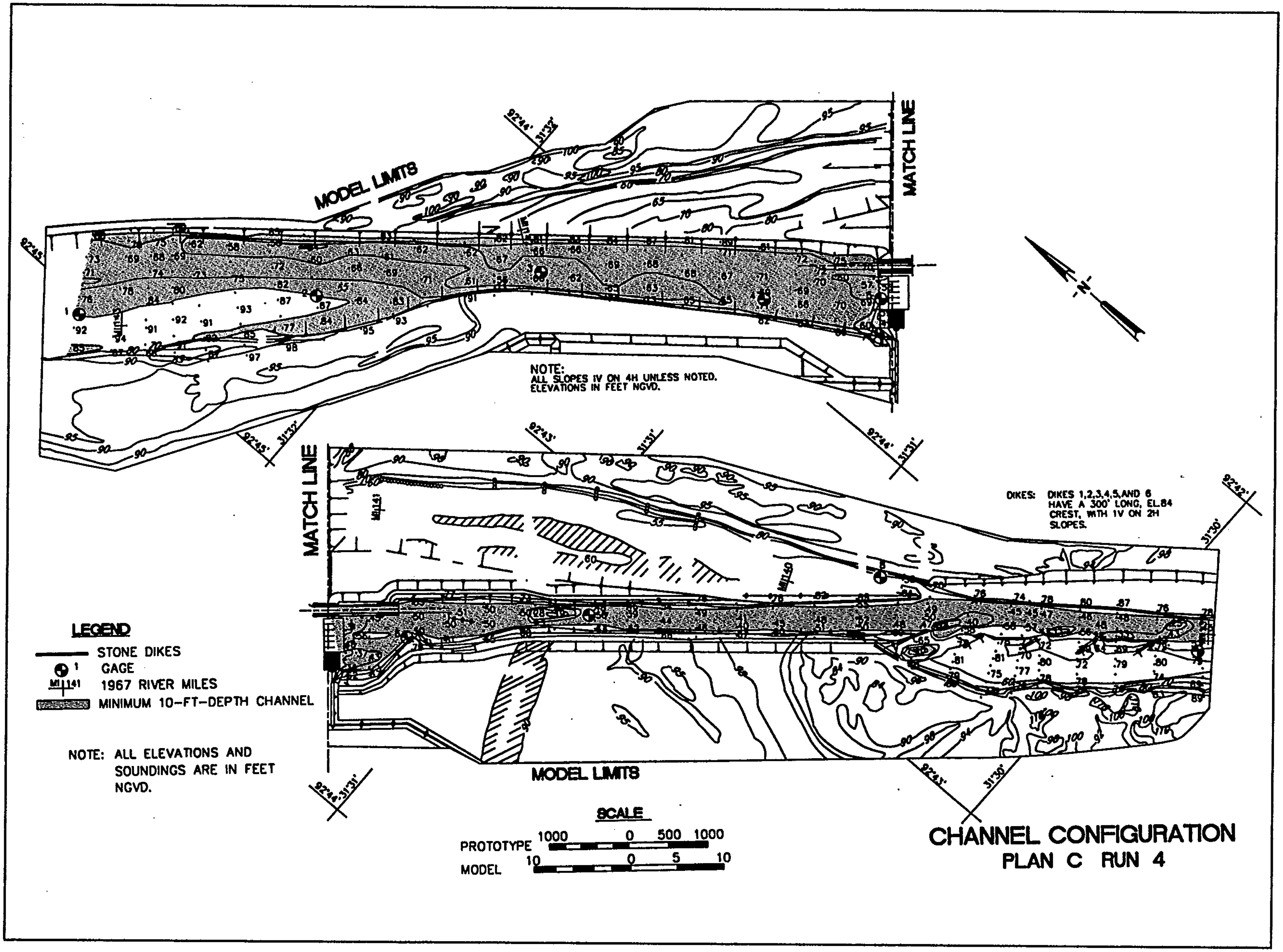


CHANNEL CONFIGURATION
PLAN B

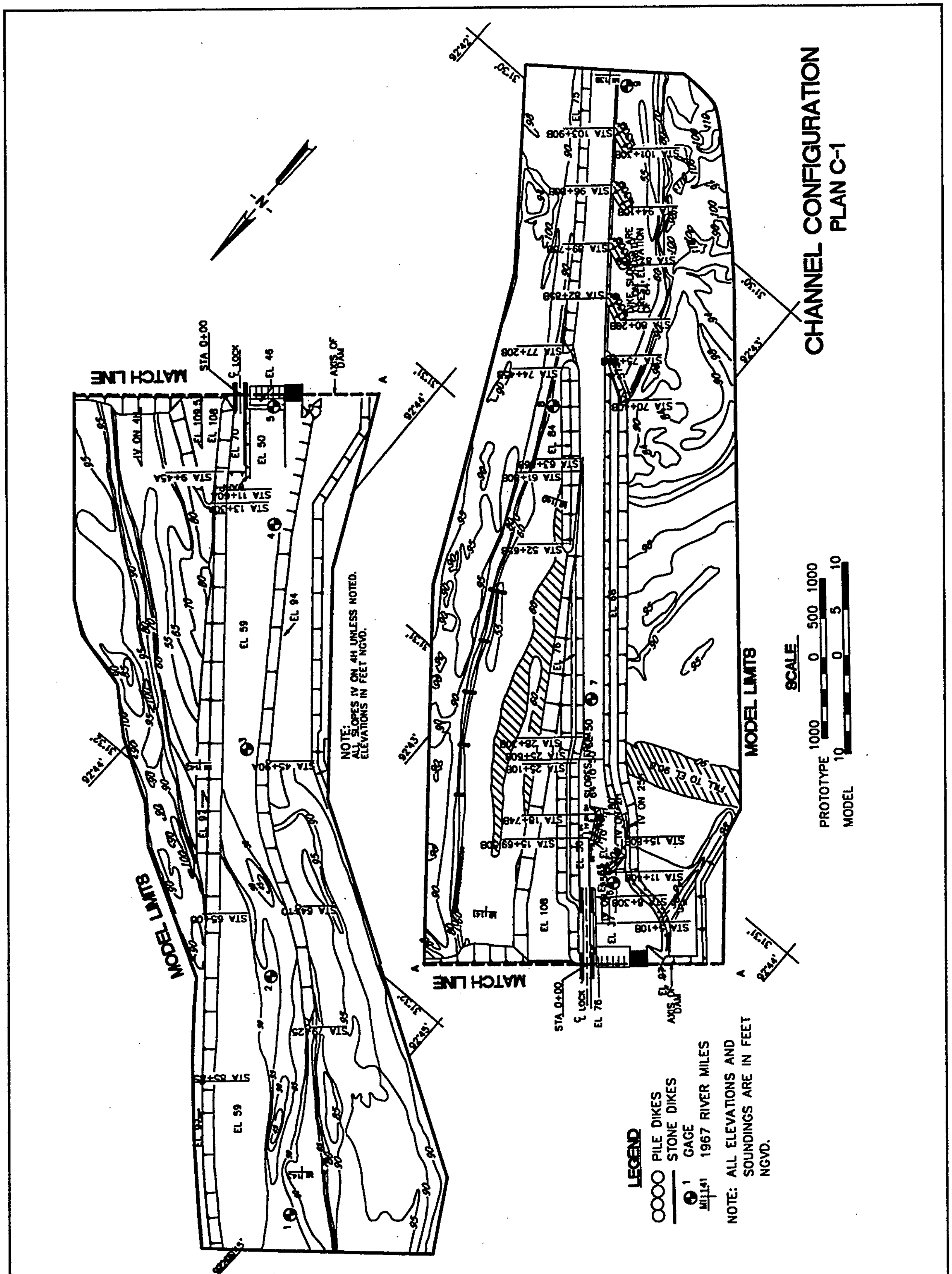


CHANNEL CONFIGURATION
PLAN B RUN 7

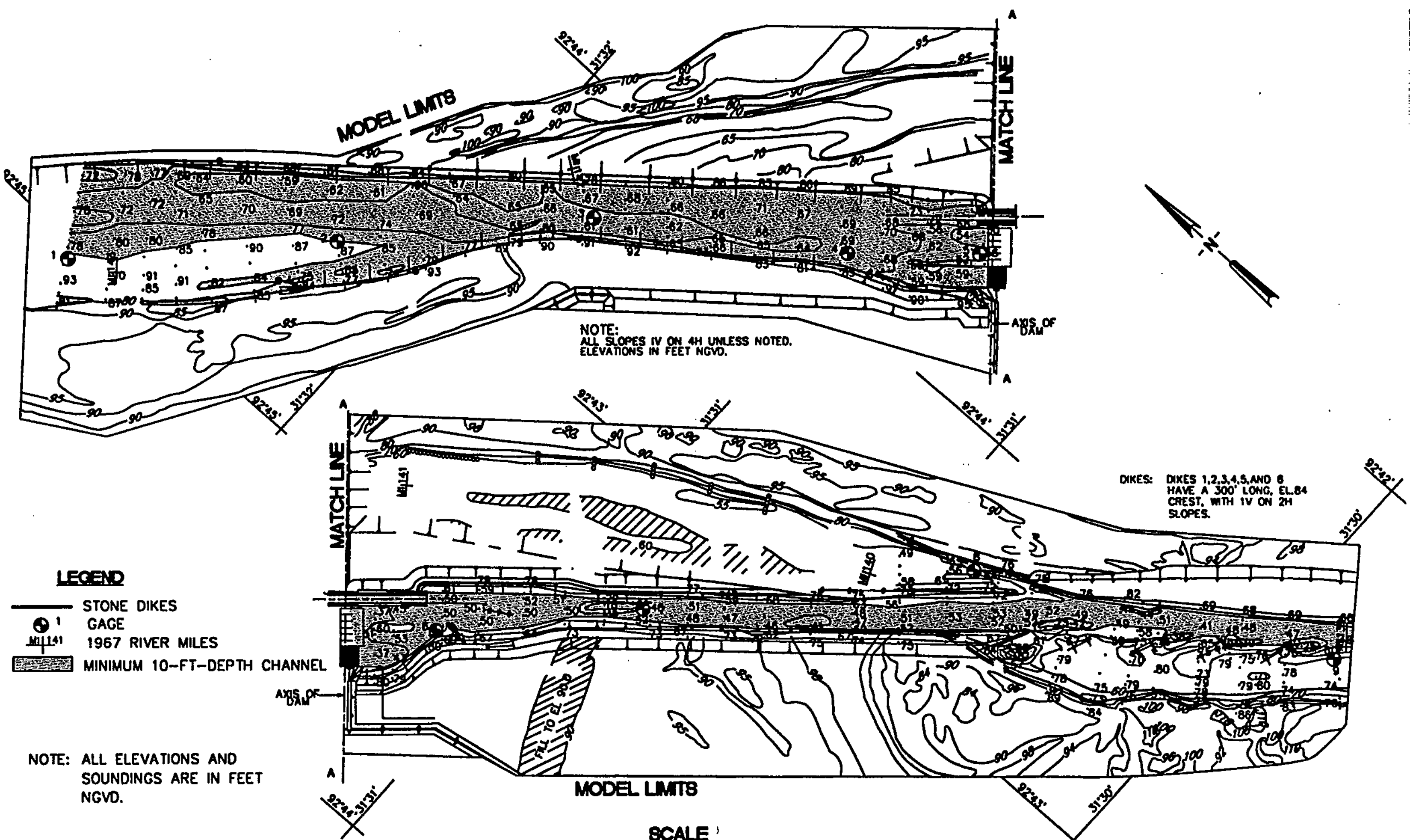

CHANNEL CONFIGURATION
PLAN C
MATCH LINE
MODEL LIMITS
STA 0+00
℄ LOCK
AXIS OF DAM
NOTE:
ALL SLOPES 1V ON 4H UNLESS NOTED.
ELEVATIONS IN FEET NGVD.
SCALE
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10
LEGEND
PILE DIKES
STONE DIKES
GAGE
1967 RIVER MILES
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.



CHANNEL CONFIGURATION
PLAN C RUN 4



CHANNEL CONFIGURATION
PLAN C-1
SCALE
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10
LEGEND
PILE DIKES
STONE DIKES
GAGE
1967 RIVER MILES
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.
NOTE: ALL SLOPES 1V ON 4H UNLESS NOTED. ELEVATIONS IN FEET NGVD.
MATCH LINE
MODEL LIMITS
STA 0+00
AXIS OF DAM



LEGEND

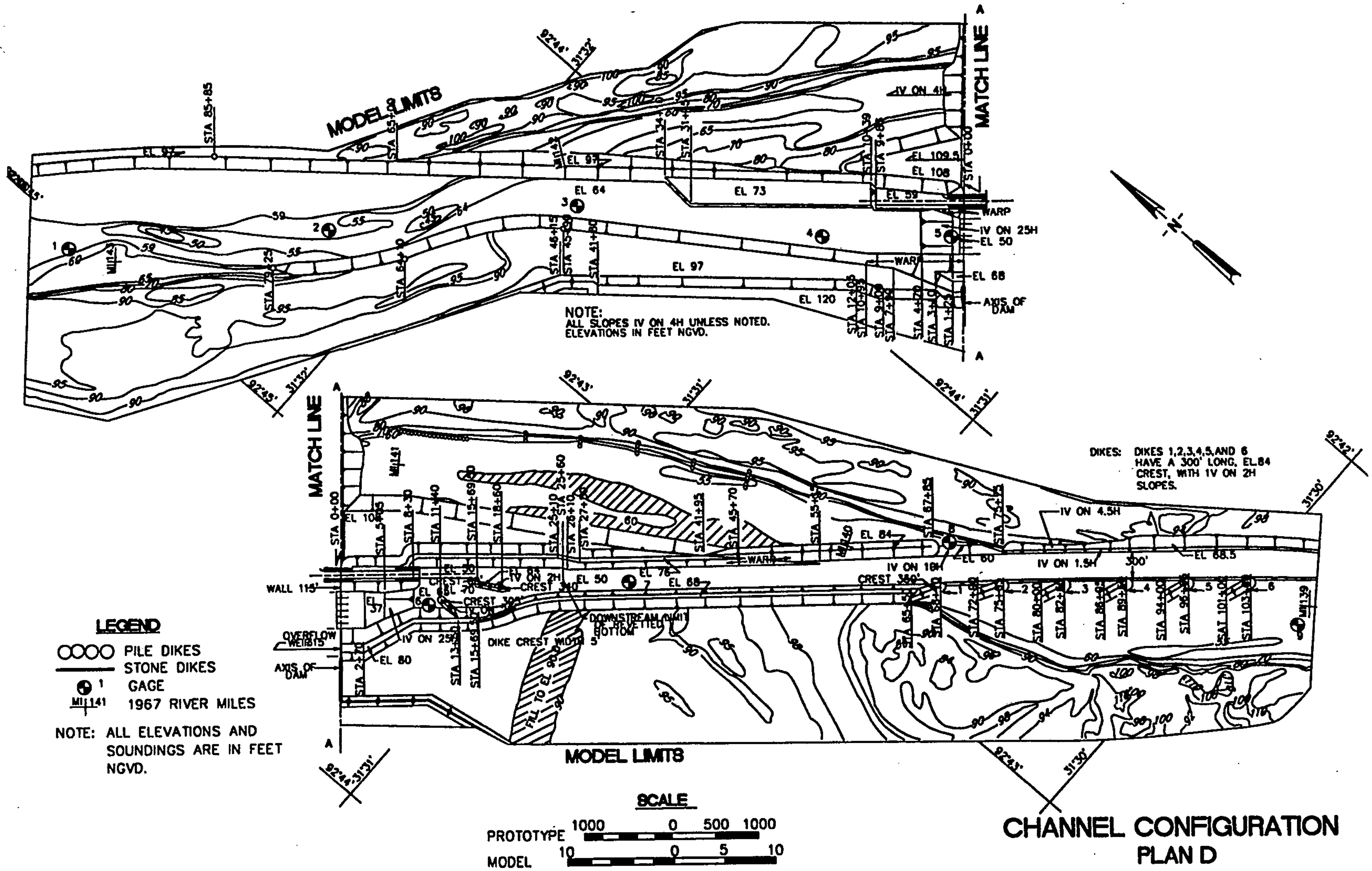
- STONE DIKES
- 1 GAGE
- MI141 1967 RIVER MILES
- MINIMUM 10-FT-DEPTH CHANNEL

NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.

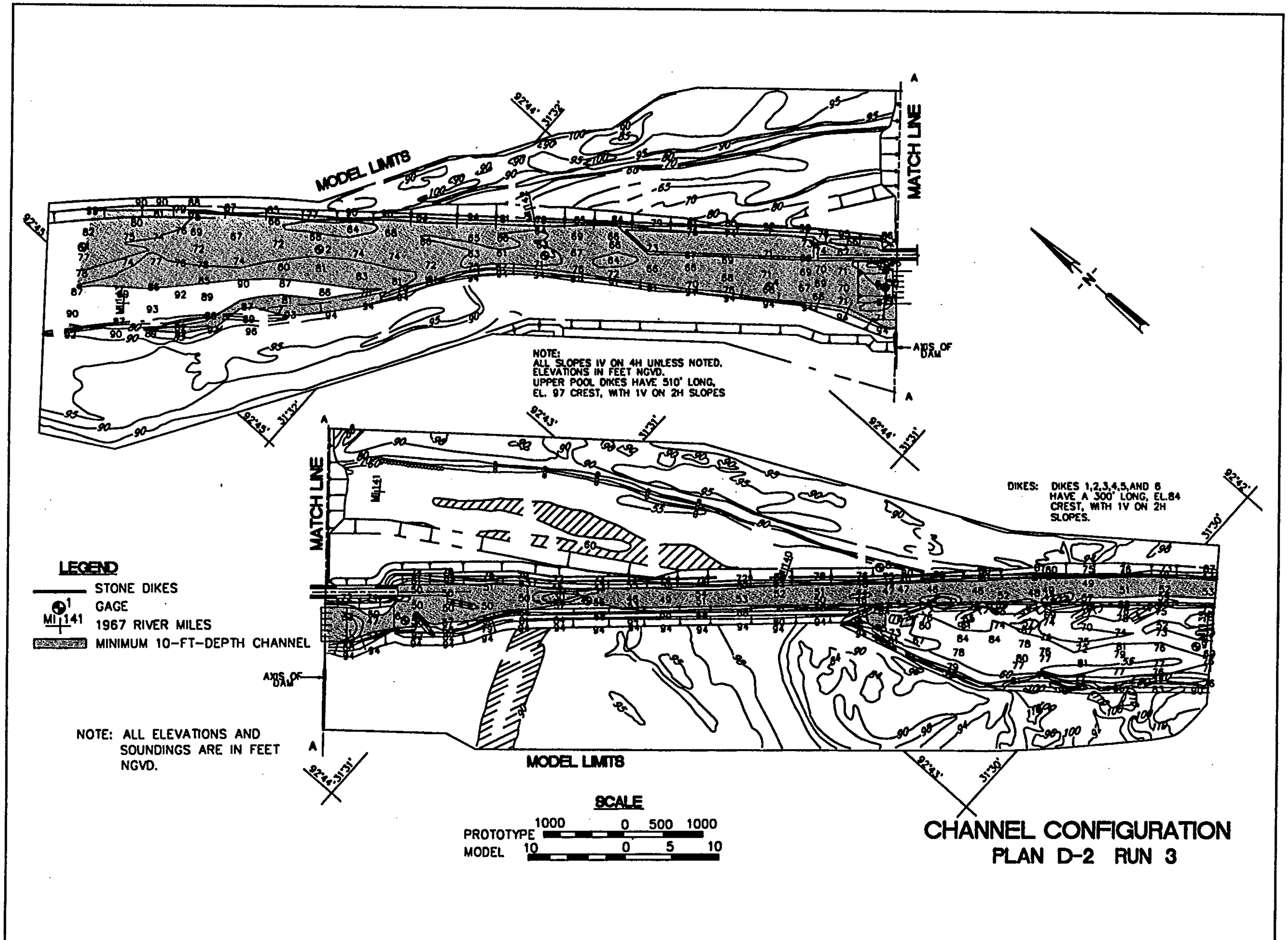
SCALE

PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10

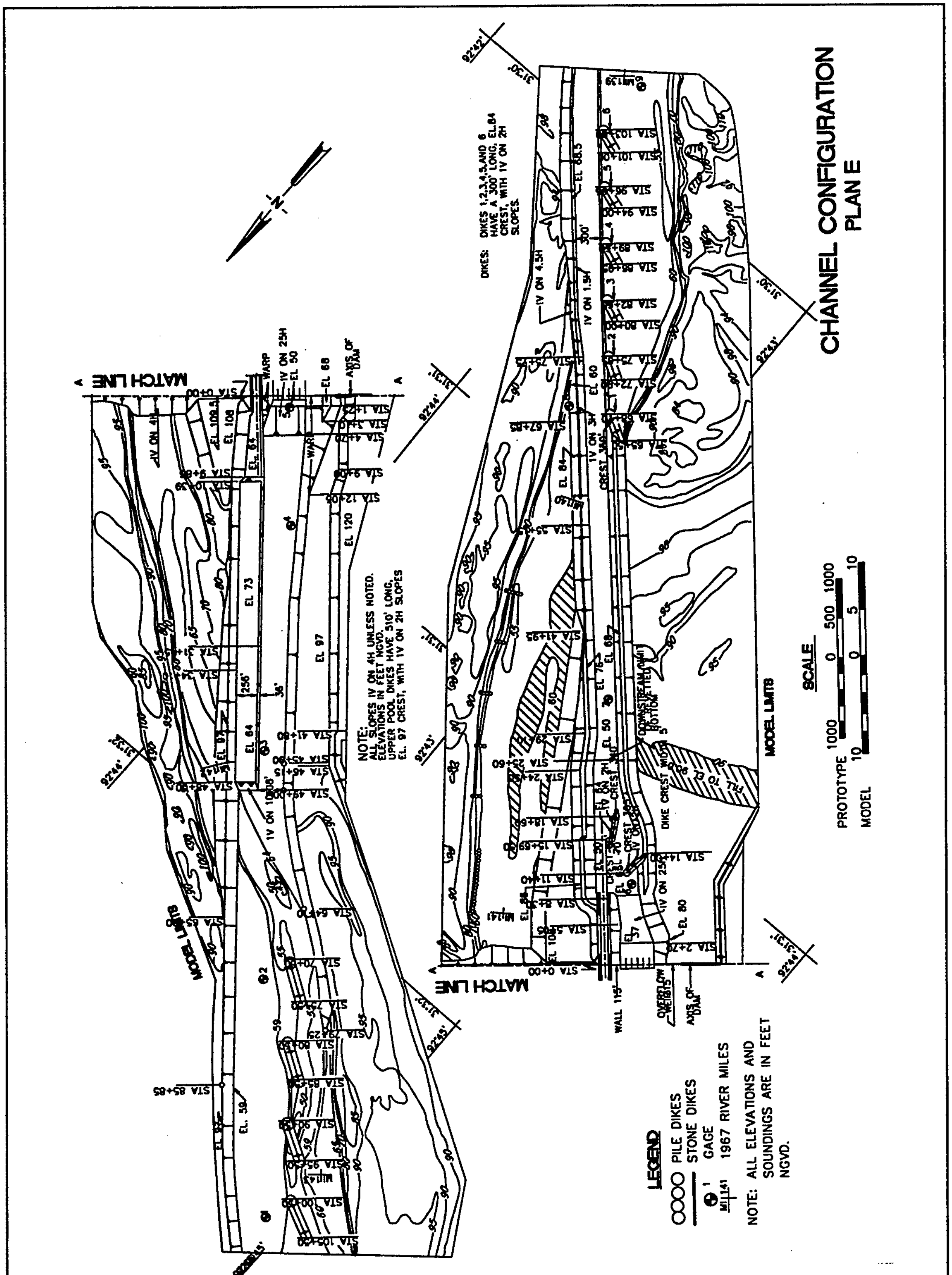
CHANNEL CONFIGURATION
PLAN C-1 RUN 4

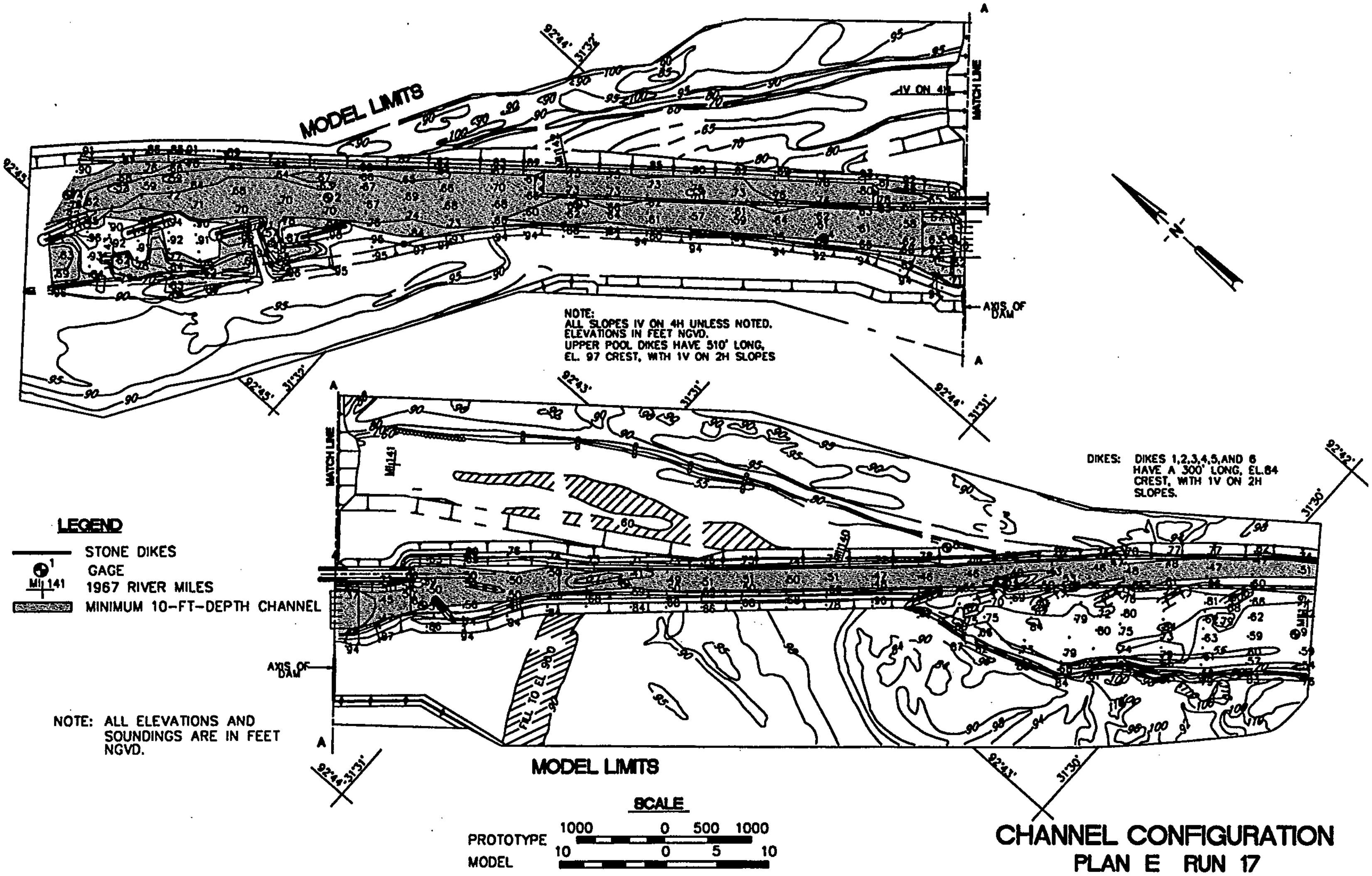


CHANNEL CONFIGURATION
PLAN D

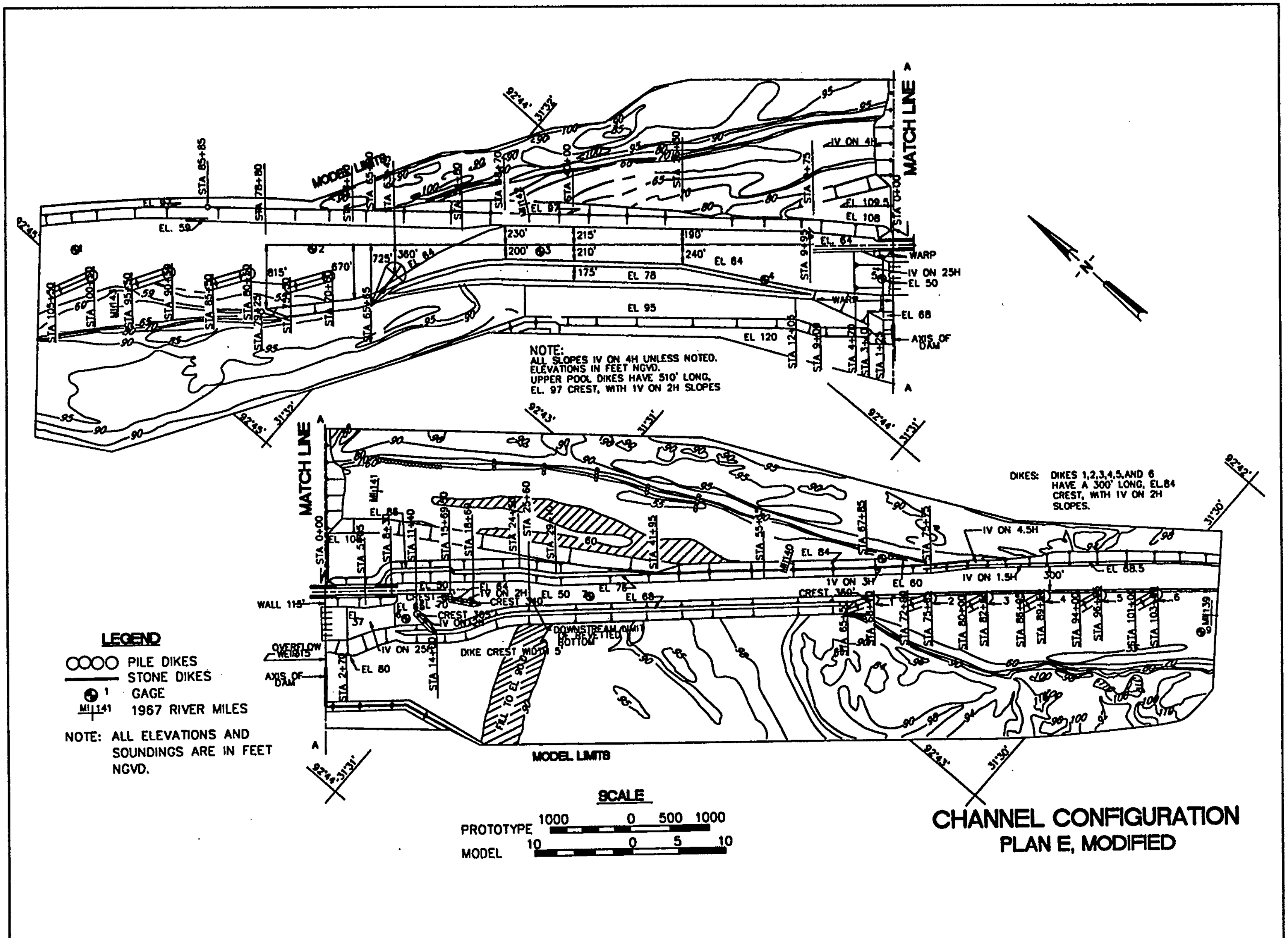


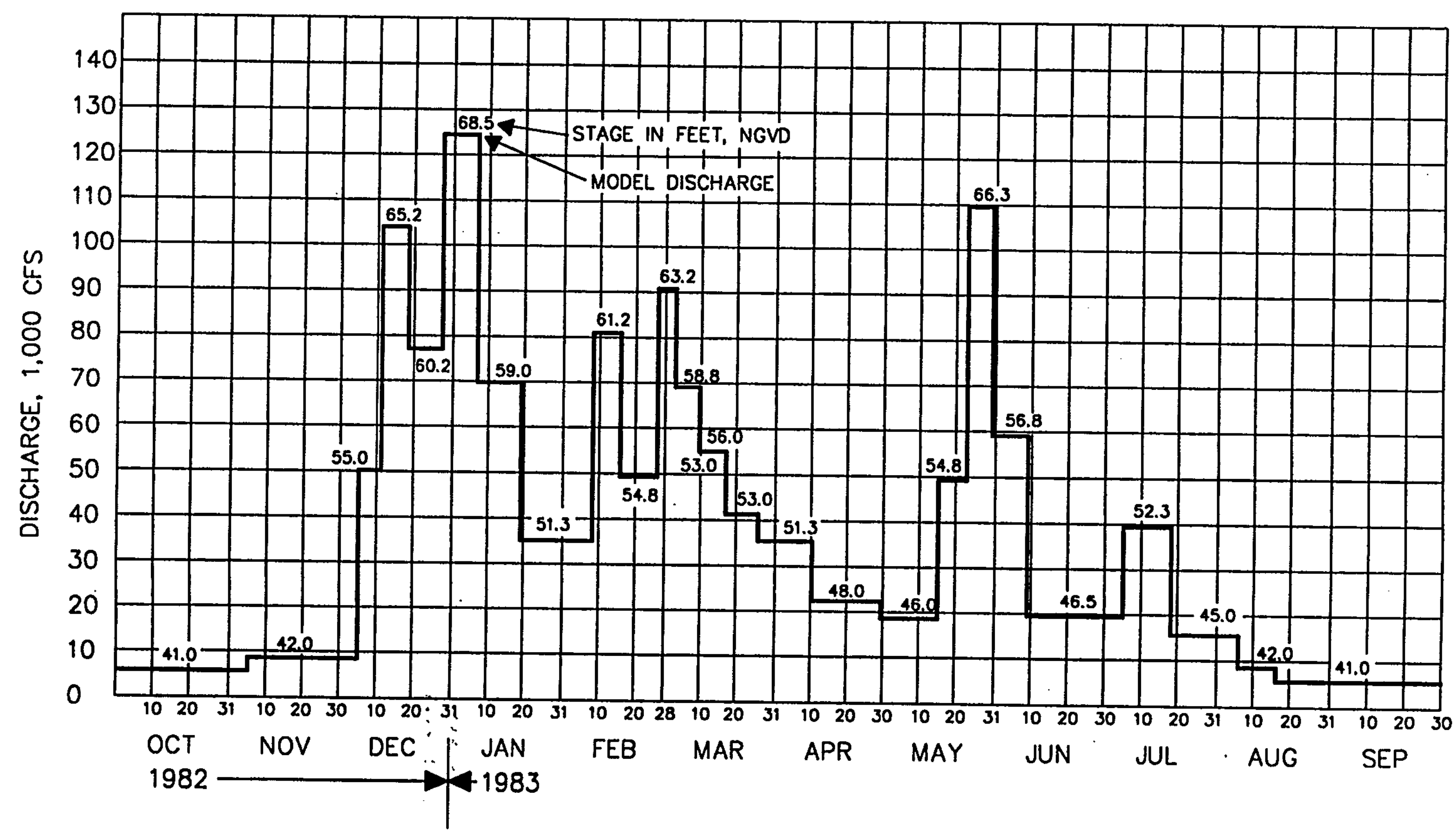
CHANNEL CONFIGURATION
PLAN D-2 RUN 3


CHANNEL CONFIGURATION
PLAN E
LEGEND
PILE DIKES
STONE DIKES
GAGE
1967 RIVER MILES
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.
NOTE: ALL SLOPES 1V ON 4H UNLESS NOTED. ELEVATIONS IN FEET NGVD. UPPER POOL DIKES HAVE 510' LONG, EL 97 CREST, WITH 1V ON 2H SLOPES
DIKES: DIKES 1,2,3,4,5,AND 6 HAVE A 300' LONG, EL 84 CREST, WITH 1V ON 2H SLOPES.
SCALE
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10
MATCH LINE
MODEL LIMITS

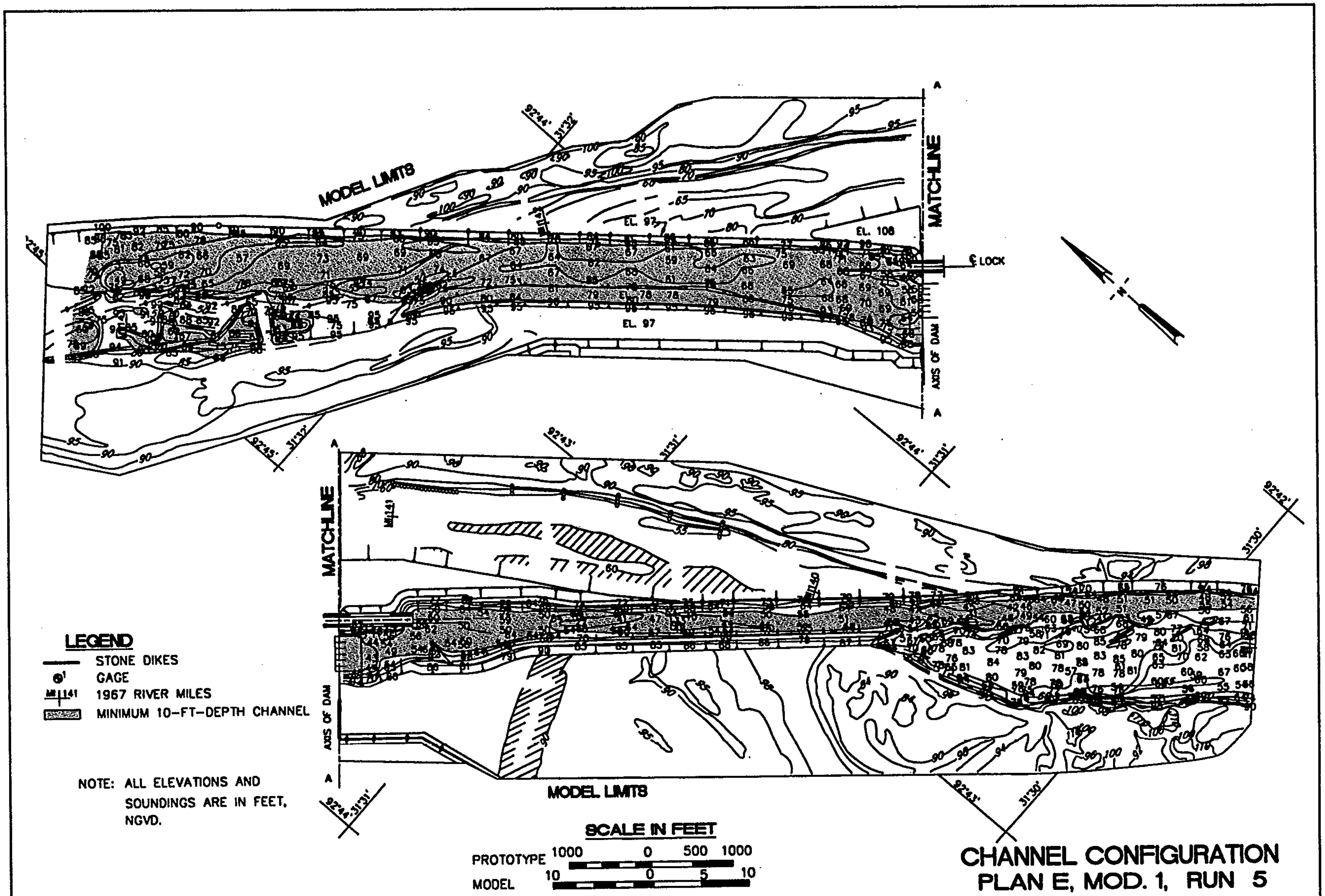


CHANNEL CONFIGURATION
PLAN E RUN 17

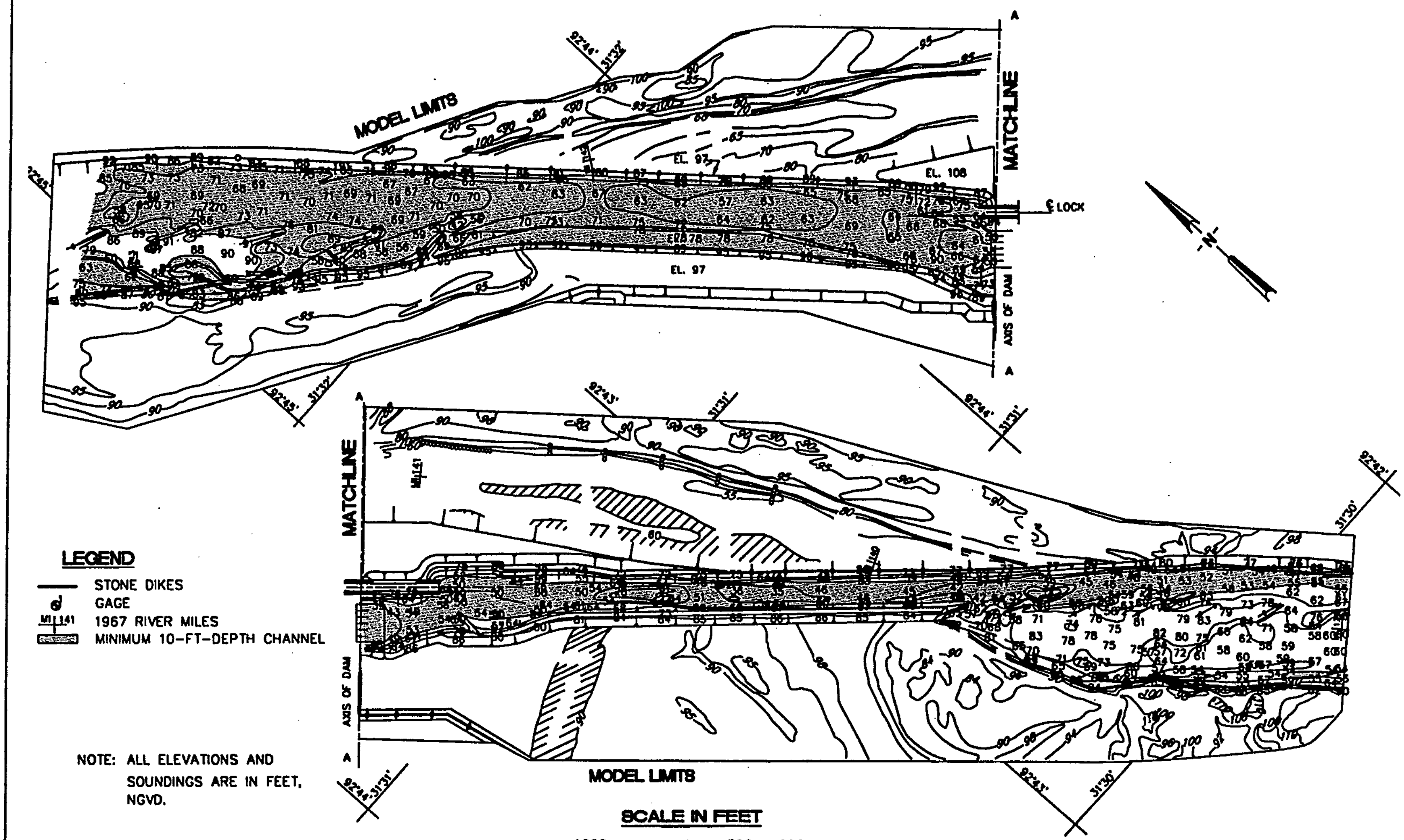

MATCH LINE
NOTE:
ALL SLOPES 1V ON 4H UNLESS NOTED.
ELEVATIONS IN FEET NGVD.
UPPER POOL DIKES HAVE 510' LONG,
EL. 97 CREST, WITH 1V ON 2H SLOPES
DIKES: DIKES 1,2,3,4,5,AND 6
HAVE A 300' LONG, EL.84
CREST, WITH 1V ON 2H
SLOPES.
LEGEND
PILE DIKES
STONE DIKES
GAGE
1967 RIVER MILES
NOTE: ALL ELEVATIONS AND
SOUNDINGS ARE IN FEET
NGVD.
MODEL LIMITS
SCALE
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10
CHANNEL CONFIGURATION
PLAN E, MODIFIED



1982-1983 HYDROGRAPH



CHANNEL CONFIGURATION
PLAN E, MOD. 1, RUN 5

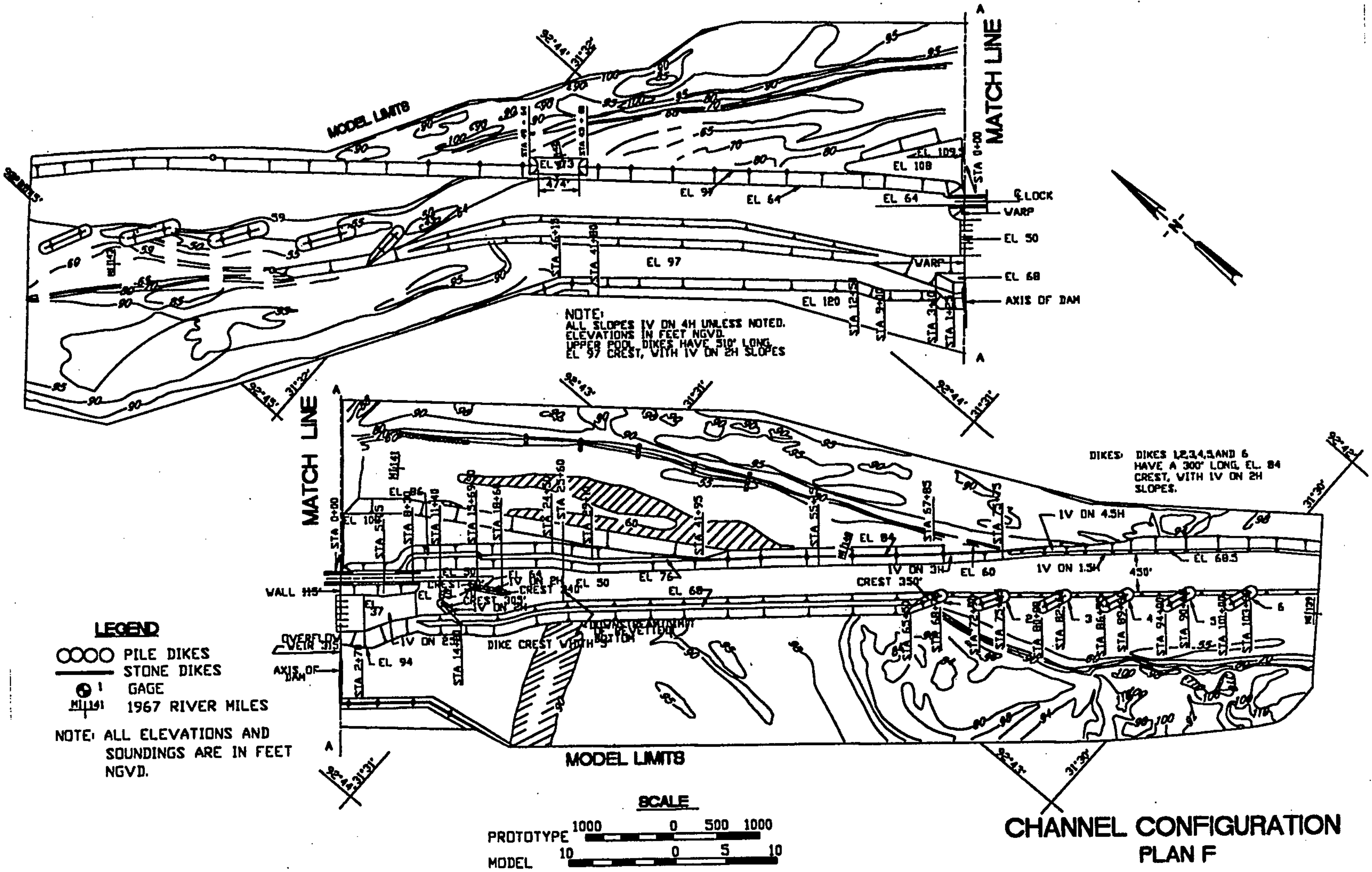


LEGEND

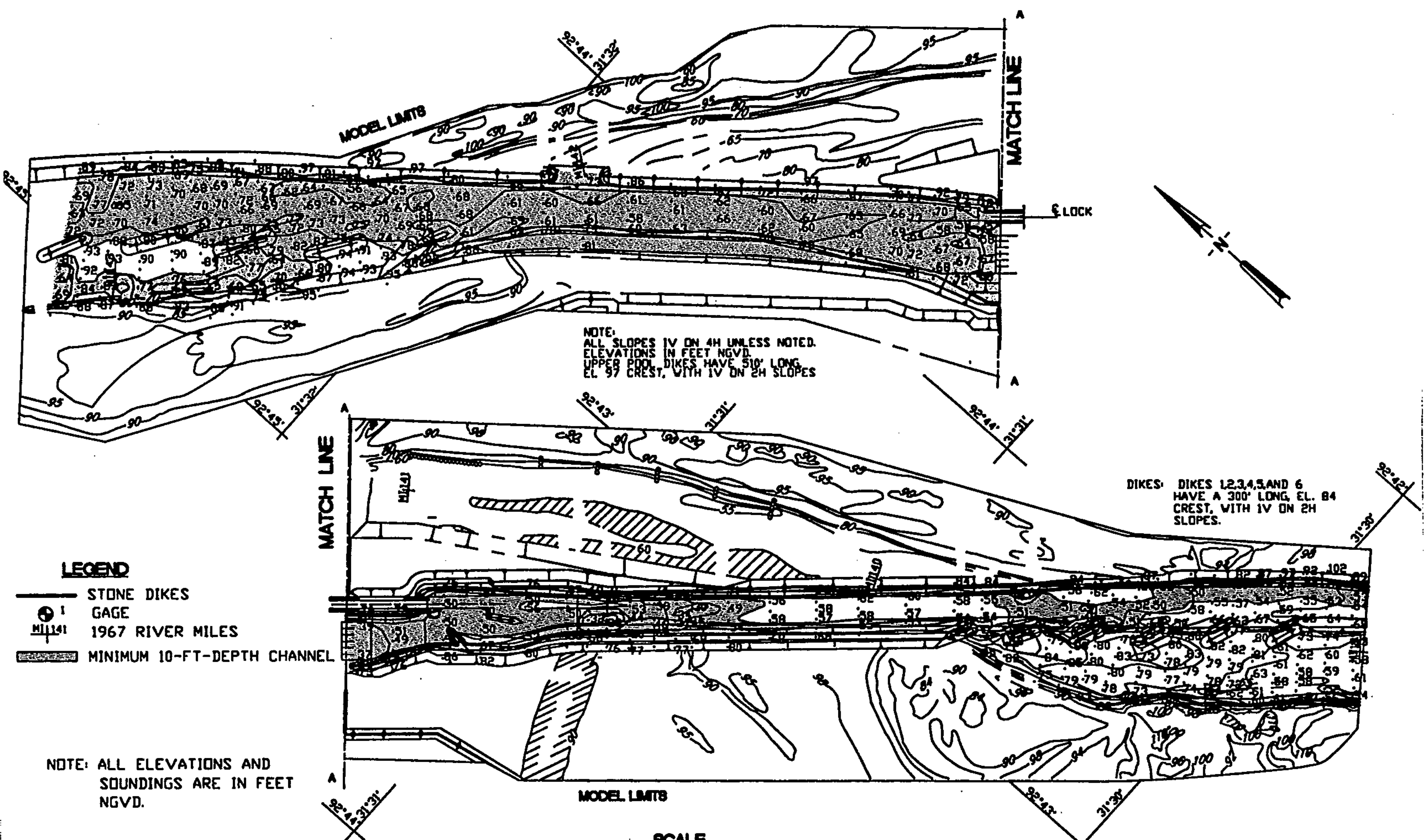
- STONE DIKES
- GAGE
- 1967 RIVER MILES
- MINIMUM 10-FT-DEPTH CHANNEL

NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET, NGVD.

CHANNEL CONFIGURATION
PLAN E, MOD. 1, T-0, RUN 5



CHANNEL CONFIGURATION
PLAN F



LEGEND

STONE DIKES
GAGE
1967 RIVER MILES
MINIMUM 10-FT-DEPTH CHANNEL

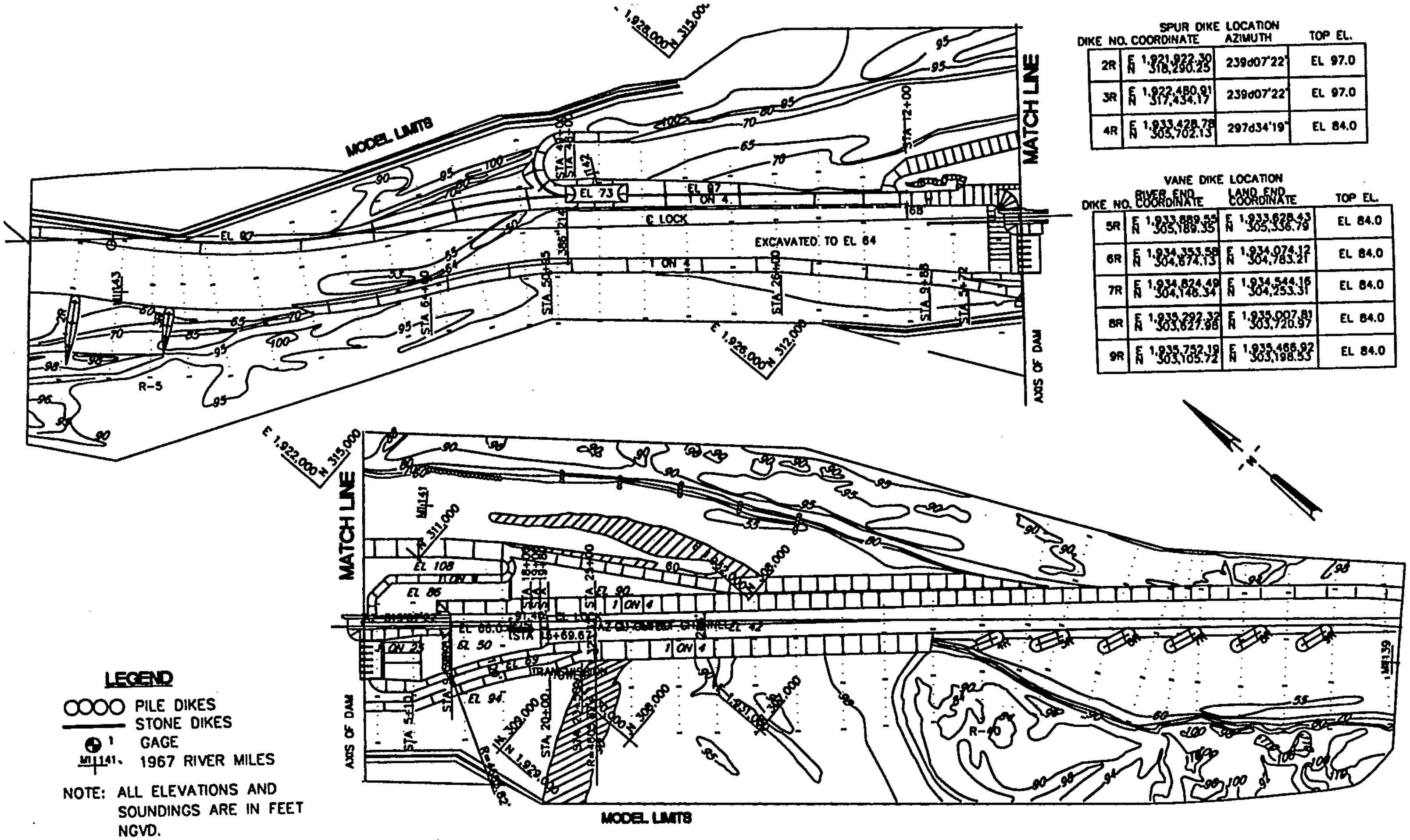
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.

SCALE

PROTOTYPE 1000 0 500 1000

MODEL 10 0 5 10

CHANNEL CONFIGURATION
PLAN F RUN 10



SPUR DIKE LOCATION DIKE NO.	COORDINATE	AZIMUTH	TOP EL.
2R	E 1,921,922.30 N 318,290.25	239d07'22"	EL 97.0
3R	E 1,922,480.91 N 317,434.17	239d07'22"	EL 97.0
4R	E 1,933,428.78 N 305,702.13	297d34'19"	EL 84.0

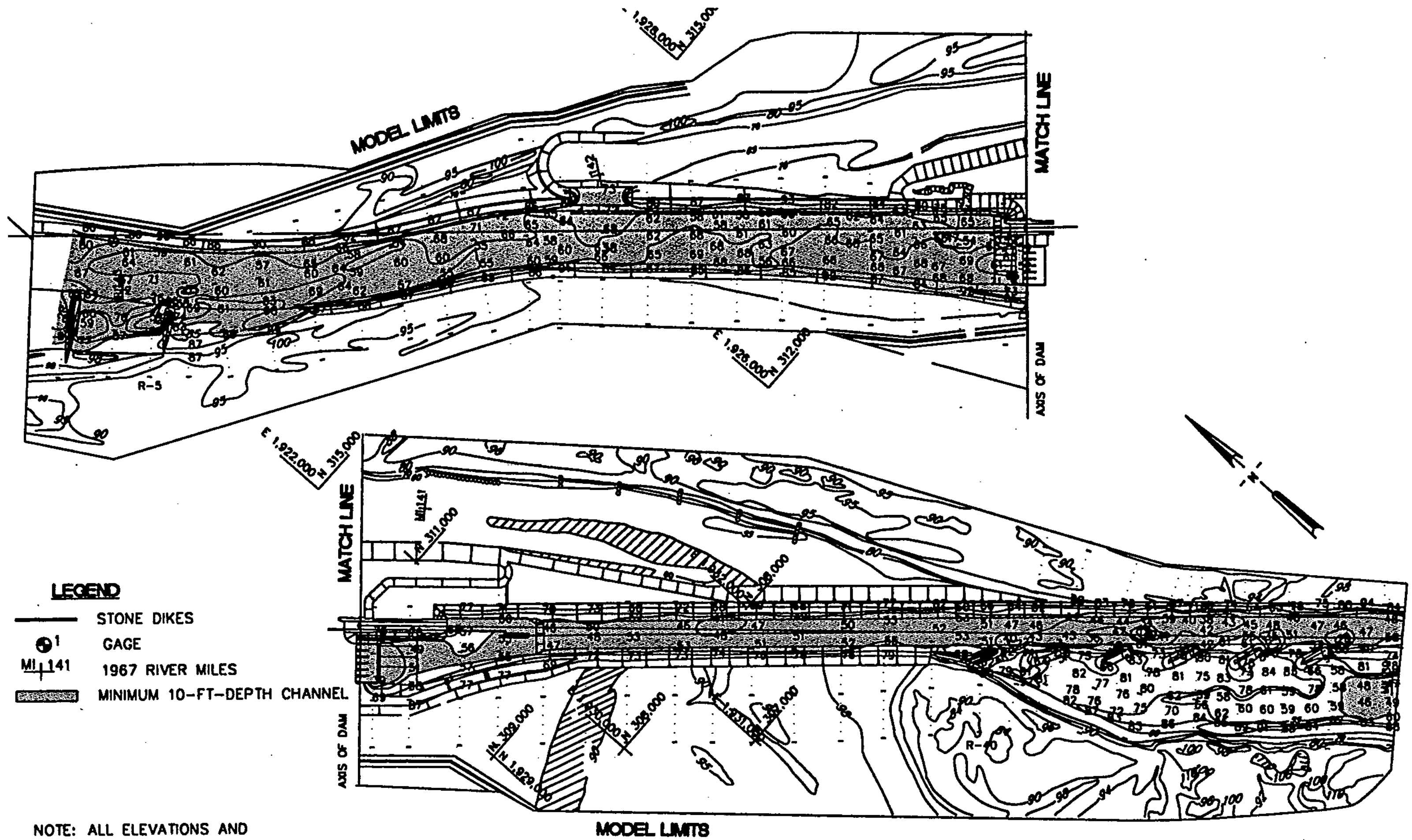
VANE DIKE LOCATION DIKE NO.	RIVER END COORDINATE	LAND END COORDINATE	TOP EL.
5R	E 1,933,889.55 N 305,189.35	E 1,933,628.43 N 305,336.79	EL 84.0
6R	E 1,934,353.58 N 304,674.13	E 1,934,074.12 N 304,783.21	EL 84.0
7R	E 1,934,824.49 N 304,146.34	E 1,934,544.16 N 304,253.31	EL 84.0
8R	E 1,935,292.32 N 303,627.98	E 1,935,007.81 N 303,720.97	EL 84.0
9R	E 1,935,752.19 N 303,105.72	E 1,935,466.92 N 303,198.53	EL 84.0

SCALE

PROTOTYPE 1000 0 500 1000

MODEL 10 0 5 10

CHANNEL CONFIGURATION
PLAN G



LEGEND

- STONE DIKES
- GAGE
- 1967 RIVER MILES
- MINIMUM 10-FT-DEPTH CHANNEL

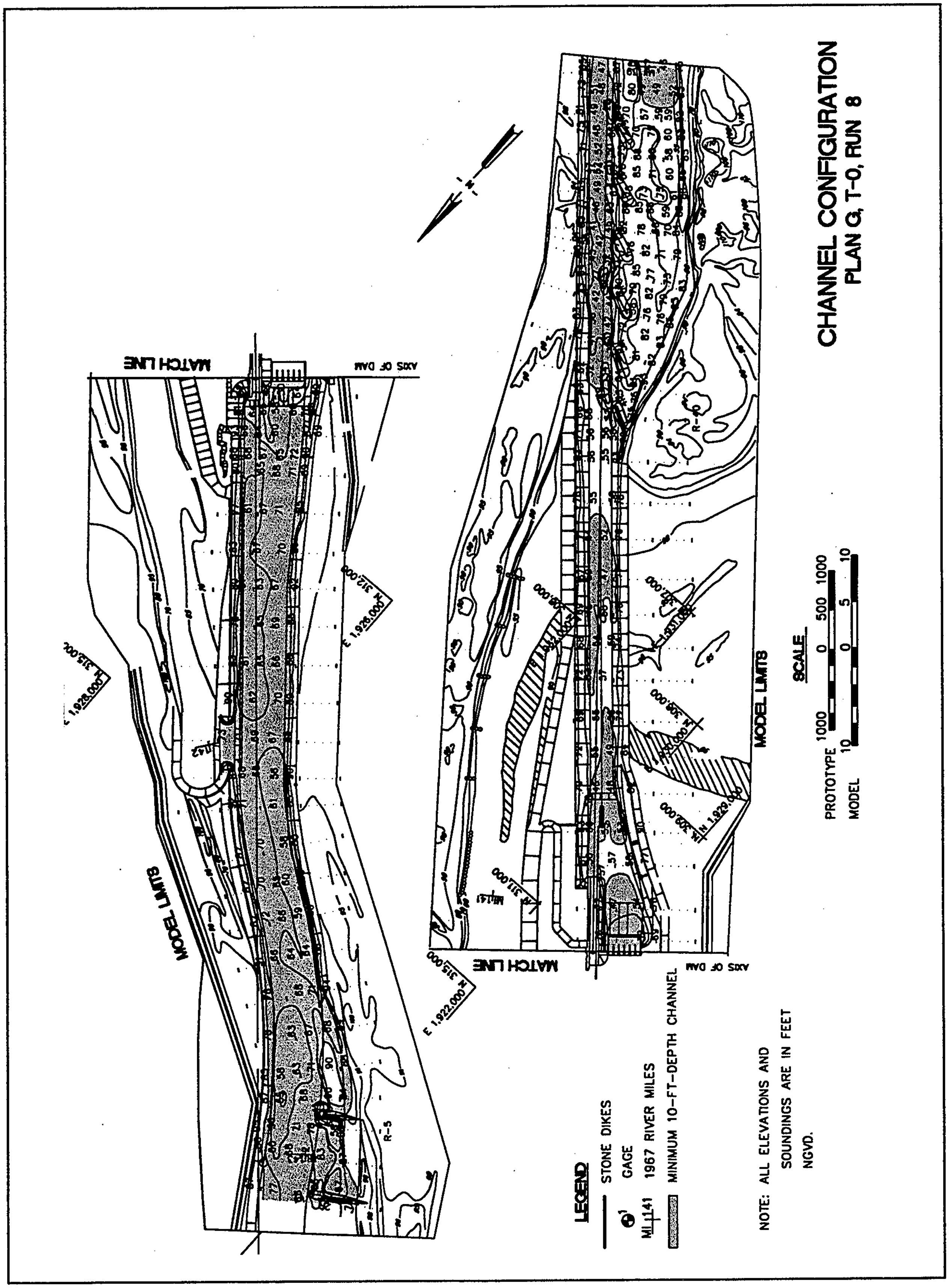
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.

SCALE

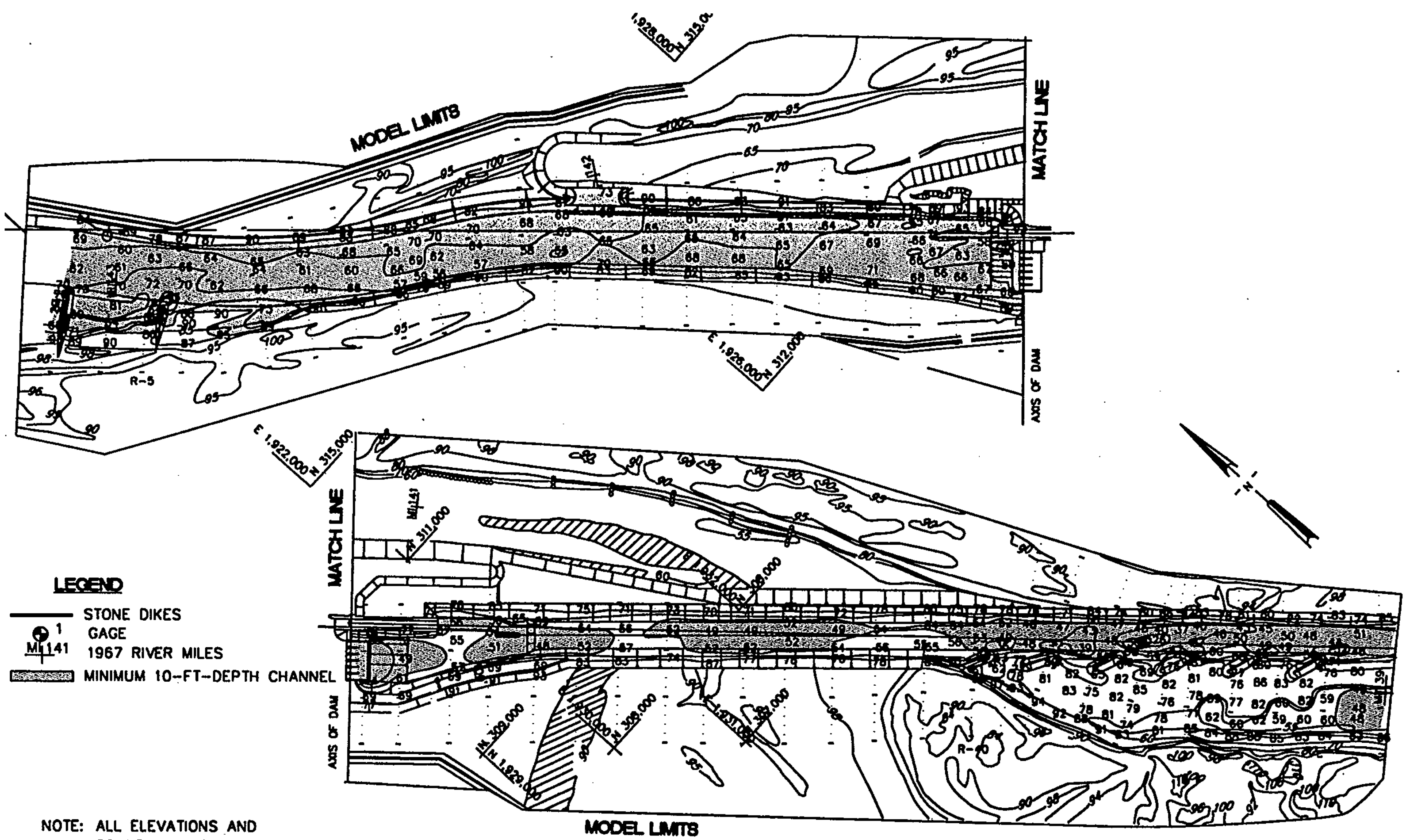
PROTOTYPE 1000 0 500 1000

MODEL 10 0 5 10

CHANNEL CONFIGURATION
PLAN G, T-0, RUN 7



CHANNEL CONFIGURATION
PLAN Q, T-0, RUN 8
LEGEND
STONE DIKES
GAGE
1967 RIVER MILES
MINIMUM 10-FT-DEPTH CHANNEL
NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.
SCALE
PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10
MODEL LIMITS
MATCH LINE
AXIS OF DAM



LEGEND

STONE DIKES
1 GAGE
M141 1967 RIVER MILES
MINIMUM 10-FT-DEPTH CHANNEL

NOTE: ALL ELEVATIONS AND SOUNDINGS ARE IN FEET NGVD.

SCALE

PROTOTYPE 1000 0 500 1000
MODEL 10 0 5 10

CHANNEL CONFIGURATION
PLAN G, T-0, RUN 11

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
July 1997

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Red River Waterway, Lock and Dam 3; Report 3, Sedimentation Conditions; Hydraulic Model Investigation

5. FUNDING NUMBERS

6. AUTHOR(S)
Randy A. McCollum

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report HL-91-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Vicksburg
4155 Clay Street
Vicksburg, MS 39180-3435

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

Lock and Dam 3, located in a cutoff channel between river miles 140.0 and 142.2 of the Red River, is designed to maintain a normal pool of el 95 (elevations (el) are given in feet referred to the National Geodetic Vertical Datum) upstream to Lock and Dam 4. The design calls for an 84-ft by 685-ft usable lock chamber and a dam with six 60-ft-wide gates.

A movable-bed model study was performed to determine the alignment of the channel and the arrangement of the lock and dam that would provide the most satisfactory channel for both navigation and sediment movement.

The movable-bed model was built to a scale of 1:120 horizontally and 1:80 vertically and reproduced the study area from river miles 143.3 to 138.9. The moveable bed was molded using crushed coal with a median grain size of 4 mm and a specific gravity of 1.30.

The original design for the lock and dam (Plan A) would not maintain an adequate navigation channel downstream of the dam. Modifications made for Plans B through F also would not provide an adequate navigation channel in the lower pool. Plan G, which used modifications developed in the fixed-bed navigation model for Plans I-3 in the upper pool and H-5 in the lower pool, maintained the navigation channel in the upper and lower pools using the average water year hydrograph. Operation of the 1958 high water year hydrograph produced shoaling in the lower pool that would impede navigation; but an average water year hydrograph performed immediately after the high water hydrograph gradually improved the shoaled areas in the lower pool.

14. SUBJECT TERMS

Dam	Navigation
Lock	Red River
Model	Sediment
Movable-bed model	Shoal

15. NUMBER OF PAGES
57

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

NSN 7540-01-280-5500

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298-102